PNWD-3226

Hydroacoustic Evaluation of Turbine Intake J-Occlusions at The Dalles Dam in 2002

FINAL REPORT

G.E. Johnson
M.E. Hanks[a]
J.B. Hedgepeth[b]
B.D. McFadden[c]
R.A. Moursund
R.P. Mueller
J.R. Skalski[d]

May 2003

Prepared for
the U.S. Army Corps of Engineers
Portland District
Portland, Oregon
under Contract DACW57-00-D-0009
Task Order No. 0009

Battelle Memorial Institute, Pacific Northwest Division
PO Box 999
Richland, Washington 99352

(a) Mevatec, Inc. North Bonneville, Washington
(b) Tenera Environmental, L.L.C., San Luis Obispo, California
(c) BioSonics, Inc., Seattle, Washington
(d) University of Washington, Seattle, Washington

Summary

The U.S. Army Corps of Engineers Portland District engaged the Battelle Memorial Institute to evaluate the performance of turbine intake occlusion plates as a smolt protection measure at The Dalles Dam from April 20 to July 12, 2002. Prototype occlusion plates with J-extensions, hereafter called J-occlusions, were deployed at Main Units 1 through 4 (MU 1-4) and plates without J-extensions were deployed at the fish units just west of MU 1-4. The J-occlusions at MU 1-4 were moved in and out in a randomized block experimental design with 3-day treatments (IN or OUT). There were seven 6-day blocks in each of the 42-day spring and summer periods. Discharge at MU 1-5, the priority units at the powerhouse, was nearly equal between treatments. Total project discharge averaged 233 kcfs (36.9% spill) and 297 kcfs (37.4% spill) during the spring and summer periods, respectively. The three sluice gates at MU 1 were open nearly continuously during the study (total discharge ~ 4.5 kcfs). Smolt passage rates were estimated from fixed-location hydroacoustic samples collected at sluiceway entrances, turbine intakes, and the spillway. To analyze the data for a treatment effect, analyses of variance were performed separately for day and night periods in spring and summer. The three response variables were total turbine passage at MU 1-4, sluiceway efficiency (SLY1-4; proportion of sluice passage out of total turbine and sluice passage at MU 1-4), and total project fish passage efficiency (FPE; proportion of non-turbine passage out of total project passage).

The results of the J-occlusion analysis were mixed (Table S.1). In spring, there were no significant differences between the IN and OUT treatments for any of the response variables, except MU 1-4 passage at night (OUT > IN). In summer, the IN/OUT differences were usually significant, but the response variable means showed a negative J-occlusion effect. Therefore, it appears that the J-occlusions did not enhance smolt protection at The Dalles Dam in 2002. This result is consistent with results from occlusion plate tests at The Dalles Dam without J-extensions in 1995 and 1996, and with J-extensions in 2001.

Table S.1. Results of J-Occlusion Evaluation

		Spring				Summer			
		Day		Night		Day		Night	
	J-Occlusions	Mean	P-value	Mean	P-value	Mean	P-value	Mean	P-value
MU 1-4	IN	55,886	0.130	45,591	0.027	82,347	0.014	74,342	0.002
	OUT	84,952		94,483		34,973		29,449	
SLY 1-4	IN	0.44	0.187	0.56	0.389	0.44	0.087	0.34	0.084
	OUT	0.56		0.52		0.65		0.44	
FPE	IN	0.62	0.568	0.57	0.911	0.52	0.550	0.41	0.527
	OUT	0.64		0.56		0.55		0.46	

Smolt movement patterns gleaned from the sonar trackers on the J-extension at the second intake of MU 4 and the piernose between MU 4 and 5 revealed that fish movement in the sample region in front of MU 4 was predominately westward regardless of the presence of J-occlusions. The Markov analysis of

movement patterns showed less westward movement and more damward movement with the J-occlusions IN than OUT in summer. Smolts 180 mm and larger were observed with the acoustic camera milling directly upstream of the trashracks of operating units. Therefore, smolt movement data for the-run-at-large from the sonar tracker and acoustic camera corroborated the lack of a positive J-occlusion effect noted above for fish passage into turbine intakes beneath the J-occlusions.

Predator fishes at MU 1 and 2 were most likely to be found near the sluiceway entrance staging just below the sill or near the pier nose. At MU 3 and 4, predators were mostly observed roaming back and forth along the powerhouse near the intake trashracks with J-occlusions OUT or near the occlusion plates with J-occlusions IN. Predator abundance was similar between seasons and IN and OUT treatments. Thus, predators seemed to present in the forebay near the face of the dam irrespective of the J-occlusions. The observation rate of predators was positively correlated with the observation rate for smolts (R^2 = 0.45, $P < 0.001$).

Horizontal distribution of fish passage was related to project operations. At the powerhouse, there was higher passage into the eastern units in summer than spring because units there were operated more in summer than spring. This pattern was also evident when fish passage was normalized by turbine flow (passage per unit discharge). It may be beneficial to summer migrants if east-end sluice gates are operated. Fish passage at The Dalles Dam in 2002 is summarized in Table S.2.

Table S.2. Fish Passage at the Dalles Dam during Spring and Summer 2002

	Sluice Efficiency[a]	Spill Efficiency[b]	Fish Passage Efficiency[c]	Sluice Effectiveness[d]	Spill Effectiveness[e]
Spring	0.25	0.45	0.69	12.96	1.22
Summer	0.11	0.38	0.50	7.62	1.03

(a) proportion of sluiceway passage out of total project passage.
(b) proportion of spillway passage out of total project passage.
(c) proportion of non-turbine passage out of total project passage.
(d) sluice efficiency divided by proportion of sluiceway discharge out of total project discharge.
(e) spill efficiency divided by proportion of spillway discharge out of total project discharge.

We reached the following conclusions from the hydroacoustic evaluation at The Dalles Dam in 2002:

1. Fish passage and spill efficiencies were lower than in previous studies.
2. Subyearling passage in the eastern half of the powerhouse was noticeable.
3. Except for MU 1-4 passage at night, turbine intake occlusion did not significantly reduce turbine entrainment in either spring or summer study periods.
4. Predators were present near the face of the dam irrespective of the presence of the J-occlusion structures.

If the region decides that spillway improvements alone will not suffice at The Dalles Dam, then we recommend work to:

1. Develop a means to protect fish at the powerhouse beyond existing sluice operation.
2. Perform an alternatives study for powerhouse bypass and/or diversion.
3. Model forebay flow patterns and relate them to dam operations.
4. Obtain basic data on smolt approach and distribution in the forebay.
5. Investigate operation of east-end sluice gates to pass subyearlings.
6. Examine use of overhead lights to enhance sluice passage.

In closing, the hydroacoustic data indicate that the J-occlusions are not a straightforward means to protect smolts at The Dalles Dam. The 2002 findings were consistent with previous studies in that the J-occlusions might perform well under certain conditions for certain fish, but not others. Given mixed performance to date for turbine intake occlusion devices, cost should influence the decision about whether to proceed with a full complement of J-occlusions at The Dalles Dam.

Preface

This research was conducted under the auspices of the U.S. Army Corps of Engineers, Pacific Northwest Division's Anadromous Fish Evaluation Program (study codes SPE-P-00-8 and SBE-P-00-017). It is related to and complements spill passage and surface flow bypass research at other dams (study codes SBE-W-96-1, SBE-W-96-2, SBE-P-00-6, and SBE-P-00-13). This study was funded by the Portland District, U.S. Army Corps of Engineers under a contract with Battelle Memorial Institute, Pacific Northwest Division (Contract No. DACW57-00-D-0009). Subcontractors to Battelle included BioSonics, Inc. (No. 412264-B-B8), Mevatec, Inc. (No. 412263-B-B8), Tenera Environmental (No. 412266-B-B8), and the University of Washington (No. 412267-B-B8).

Acknowledgments

We earnestly acknowledge contributions to this study by:

- U.S. Army Corps of Engineers, contracting officer's technical representatives: Blaine Ebberts and Dan Feil
- U.S. Army Corps of Engineers personnel – Bob Cordie, Steve Dingman, Dick Harrison, Larry Lawrence, Rock Peters, Norm Tolonen, and Miro Zyndol
- Battelle staff – Dennis Dauble, Traci Degerman, Al Garcia, Terri Gilbride, Kenneth Ham, Fenton Khan, Kathy Lavender, Nate Phillips, Gene Ploskey, Marshall Richmond, Cindy Rakowski, John Serkowski, Scott Titzler, and Mark Weiland
- BioSonics, Inc. – Eddie Kudera, Colleen Sullivan, and Shui Yang
- Honald Crane Services – Bob Austin and Mike Honald
- Mevatec, Inc. – Kyle Bouchard, Kathy Chandler, Charlie Escher, Chris Holzer, Peter Johnson, Jina Kim, Deborah Patterson, Julie Rowlands, Carl Schilt, Keri Taylor, and Shon Zimmerman
- Schlosser Machine Shop – Vinnie Schlosser and staff
- University of Washington, Applied Physics Laboratory – Ed Belcher and Bill Hanot.

Contents

Figures

Tables

1.0 Introduction

Development of long-term measures to protect juvenile salmon at The Dalles Dam (Figure 1.1) is a high priority in the endeavor to increase smolt survival through the Federal Columbia River Power System (FCRPS) (National Marine Fisheries Service 2001). The Dalles Dam does not have turbine intake screens, so the only non-turbine passage routes for downstream migrants are the sluiceway and spillway. Estimates of project-wide fish passage efficiency (FPE[a]) range from 32% to 94% depending on the percentage of spill among other factors (Ploskey et al. 2002). Thus, there is a need to improve FPE at this critical passage location in the Columbia River.

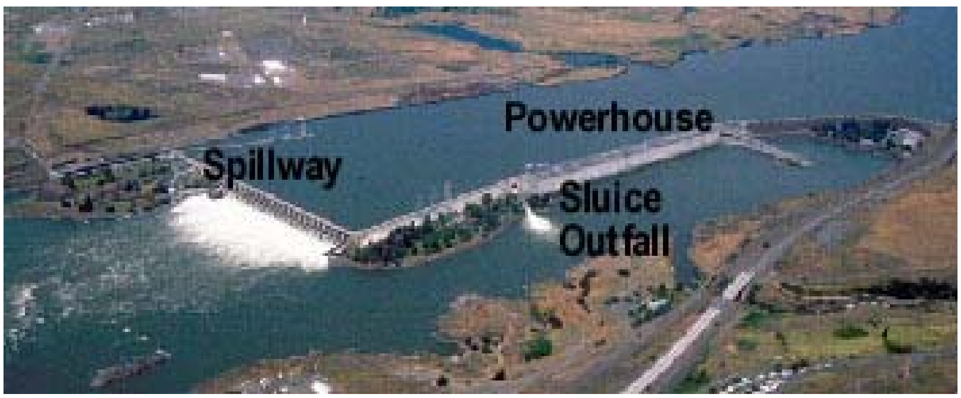


Figure 1.1. Aerial Photograph of The Dalles Dam. Flow is from right to left. The prototype J-occlusions deployed at Main Units 1-4 are on the left side of the powerhouse above the sluice outfall.

1.1 Background

In 2002 at The Dalles Dam (TDA), prototype turbine intake occlusion plates with J-shaped extensions[b] were evaluated as a new means of preserving juvenile salmon. The occlusion plates covered the upper half of the intakes at Fish Units 1-2 and Main Units (MU) 1-4. When coupled with J-extensions protruding 25 ft from the bottom of each plate, the "J-occlusions" (Figure 1.2) were to cause the turbines to draw water from deeper in the forebay than would otherwise be the case. The bioengineering premise was that deepening the turbine flow net would decrease entrainment into turbines of juvenile migrants naturally distributed vertically in the upper part of the water column, thereby increasing smolt survival.

[a] FPE is calculated as non-turbine passage divided by total passage.
[b] In this report, we call the combination of occlusion plate and J-extension structures a "J-occlusion."

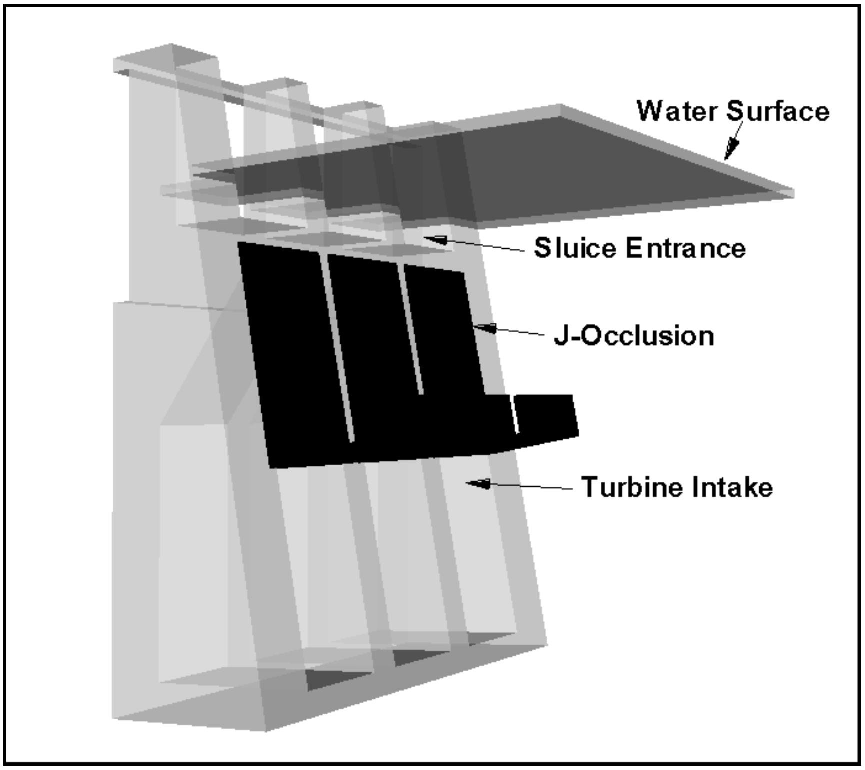


Figure 1.2. Perspective Drawing of TDA Powerhouse Unit 1 Showing the Water Surface, Sluice Entrance, J-Occlusion, and Turbine Intake

Prior to 2002, turbine intake occlusions had been tested with mixed results at Bonneville, Wanapum, Lower Granite, and The Dalles dams. At Bonneville Dam First Powerhouse in 1996, the upper half of turbine intakes at Units 3 and 5 was occluded to intensify and deepen the "zone of separation" between turbine and sluiceway flow nets in an attempt to decrease turbine passage and increase sluiceway passage. Ratios of mean passage rates with and without occlusion plates were 4.8 (with:without) for sluice entrances and 0.56 (with:without) for turbine intakes, but the results were not statistically significant because daily passage was highly variable (Ploskey et al. 1998). At Wanapum Dam, the surface attraction structure on the forebay side of the powerhouse essentially occluded the upper 20% of the turbine intakes. Apparently an indirect effect of this structure was reduced entrainment rates into turbine intakes below it (Kumagai et al. 1996). At Lower Granite Dam in 1998, a simulated wells intake (SWI) was retrofit on the existing surface bypass and collector structure to occlude the upper 20% of intakes at Units 4-6. A fish budget analysis of juvenile passage from hydroacoustic data suggested that the SWI reduced turbine passage because fish budget entrainment coefficients in 1998 were one-sixth of those in 1997 without the SWI (Dauble et al. 1999).

At The Dalles Dam, occlusion plates were first deployed in 1995. No significant difference in sluiceway efficiency with and without occlusion plates was observed (Nagy and Shutters 1995). In 1996, the same occlusion plates were evaluated again, but the results were inconclusive, mainly because of difficulty estimating turbine passage downstream of the occlusions (BioSonics 1996). The 1995 and 1996 tests involved only occlusion plates over the upper half of the turbine intakes at Main Units 1-5. In 2001, J-extensions were added (MU 1-4 only) with the objective of deepening the turbine flow net. Results from the 2001 J-occlusion test, however, were compromised because the experimental design was not realized as the treatment conditions were disrupted by abnormal project operations in an unusually low flow year (Moursund et al. 2002).

In conclusion, the collective results of occlusion plate tests suggest the need for a definitive test of the premise that occluding the upper portion of turbine intakes and deepening the turbine flow net will decrease turbine passage. Accordingly, research on the J-occlusions at The Dalles Dam was a high regional priority in 2002.

1.2 Goals and Objectives

The primary goal of this study was to evaluate turbine intake occlusions as a smolt protection measure at The Dalles Dam. A secondary goal was to provide route-specific passage rates for others to use in project survival estimates. We collected hydroacoustic data on smolt passage at The Dalles Dam from April 20 to July 12, 2002. In a complementary effort, other researchers used radio telemetry to study fish passage and assess performance of the J-occlusions (Beeman et al. 2002).

The objectives of the hydroacoustic study are as follows, organized by the two main areas of research, fish passage and J-occlusion evaluations.

Fish Passage Evaluation

1. Optimize transducer deployments at sluiceway entrances to sample fish that are committed to passing when detected.
2. Use spilt-beam transducer deployments at each passage route to validate the assumptions of the acoustic screen passage model.
3. Estimate passage rates of juvenile salmon at each passage route (individual turbines, spill bays, and sluiceway entrances) and relate passage rates to discharge rates.
4. Estimate proportions of fish passing through the spillway, turbines, and sluiceway.
5. Describe the spatial and temporal distributions of fish passage at the powerhouse and spillway.

J-Occlusion Evaluation

6. Assess the effect of the J-occlusions on fish passage by statistically comparing fish passage metrics, especially passage at MU 1-4, with and without J-occlusions.
7. Assess potential "edge effects" at MU 4/5 relative to J-occlusions by evaluating differences in turbine passage, fish density, and/or fish movement patterns at MU 4/5 during J-occlusion treatments.
8. Describe fish movement and vertical distribution patterns in front of MU 4 with and without J-occlusions.
9. Record the presence/absence and behavior of juvenile salmon and predator fishes in the vicinity of the J-occlusions and at gaps between adjacent J-occlusions.

1.3 Report Content

This report has eight sections and four appendices. The study site is described in Section 2. The methods are explained in Section 3. The results are presented in two sections: Section 4, fish passage evaluation, and Section 5, J-occlusion evaluation. The data are discussed in Section 6. Conclusions and recommendations are given in Section 7, and literature cited is listed in Section 8. Appendix A contains a synopsis of the statistical methods, Appendix B has sonar tracker methods, Appendix C describes acoustic camera methods, and Appendix D provides responses to comments on the draft final report.

2.0 Study Site Description

2.1 General

The Dalles Dam, located at river mile 192, is the second closest dam in the FCRPS to the Pacific Ocean. It has a 2,090-ft-long powerhouse with 22 turbine units, a total generating capacity of 1,814 MW, and total hydraulic capacity of 1,375 kcfs. Full pool elevation is rated at 160 ft above mean sea level and minimum operating pool elevation is 155 ft. The sill at each sluiceway entrance is at elevation 151 ft. The turbine intake ceiling intersects the trash racks at elevation 141 ft. The face of the dam is 11.3° off vertical (Figure 2.1). The 1,381-ft-long spillway is comprised of 23 bays with radial gates. The thalweg is along the south shore and there are deep areas in front of the powerhouse (Figure 2.2), although much of the forebay is relatively shallow (< 65 ft deep).

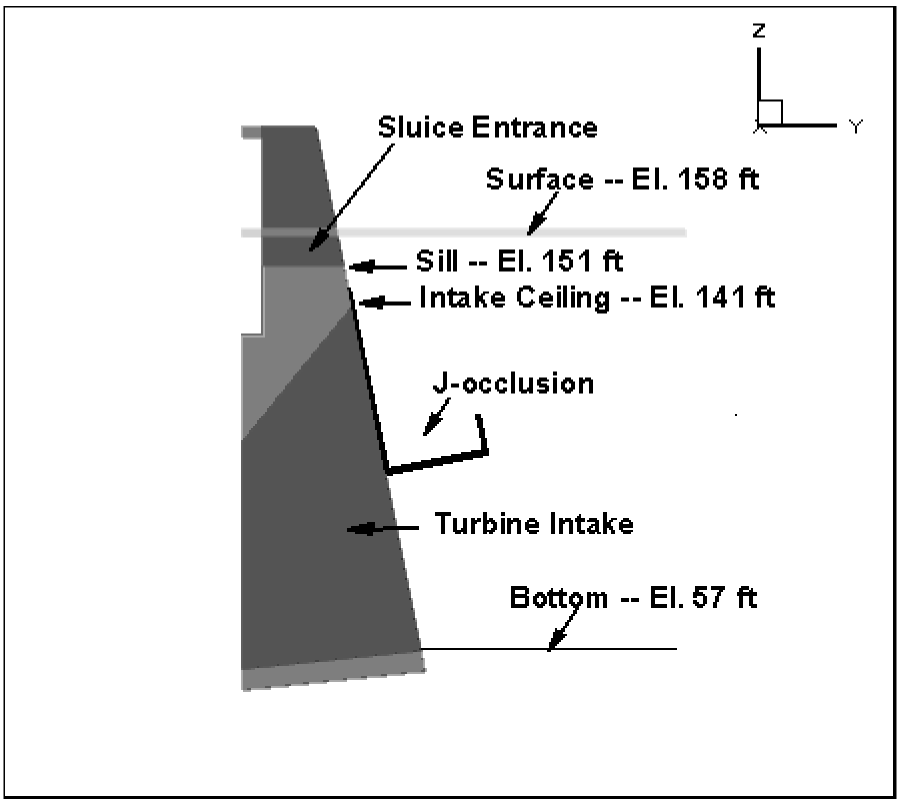


Figure 2.1. Sectional View of The Dalles Dam Powerhouse Showing Sluiceway Entrance, Sill, Intake Ceiling, J-Occlusion, and Turbine Intake

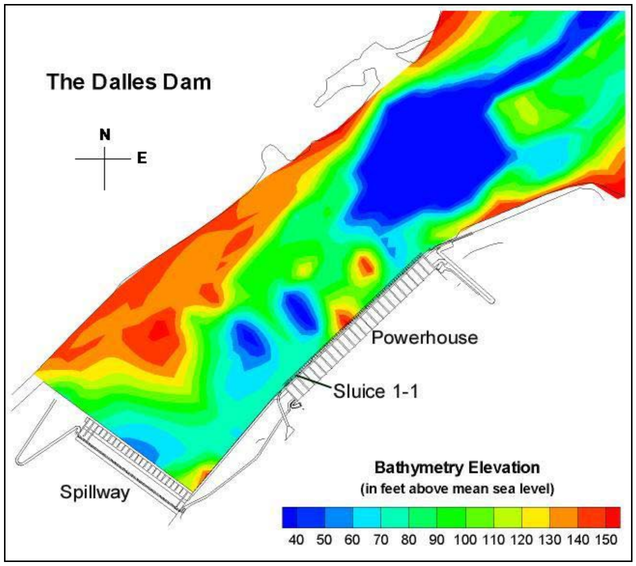


Figure 2.2. Plan View of The Dalles Dam Showing Forebay Bathymetry

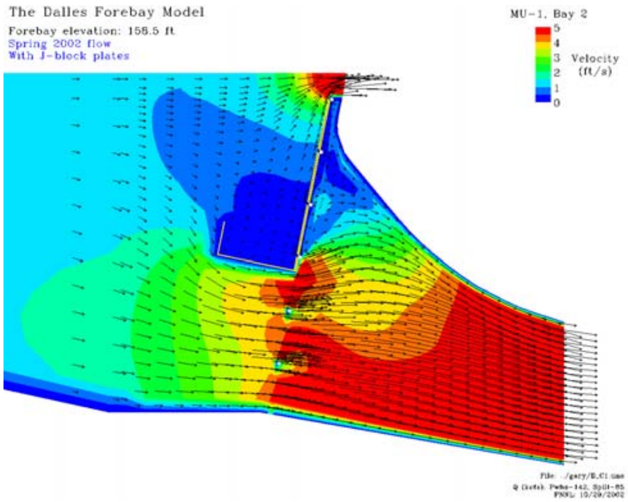
2.2 Sluiceway

The ice and trash sluiceway extends the entire length of the powerhouse. During the fish passage season (April through November), typically the three sluice gates at Main Unit (MU) 1 are opened. This operation is based on previous research (e.g., Nichols and Ransom 1980). The capacity of the sluiceway is limited hydraulically to about 4,750 to 5,000 cfs because of a constriction in the downstream end of the channel near where it exits the powerhouse. Water enters the sluiceway from the forebay when motorized hoists move leaf gates off the sill at elevation 151 ft. Sluiceway discharge is a relatively small proportion of total project discharge (~1-5%).

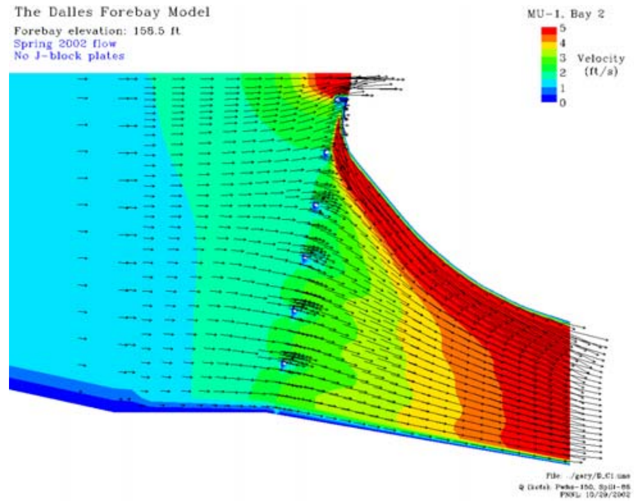
2.3 J-Occlusions

The J-occlusion plates were lowered in front of existing trashracks at MU 1-4, thereby blocking or preventing flow from entering MU 1-4 turbine intakes above elevation 100 ft. Various shapes of blocked trashracks for The Dalles Dam were studied in physical models at the Corps of Engineers Engineering Research and Development Center (ENSR 2001). A J-shaped blocked trashrack appeared to be the most effective in creating flow conditions thought favorable for collection of juvenile fish in the ice and trash sluiceway. Figures 1.2 and 2.1 show gross details of the J-occlusions installed at The Dalles Dam in 2002. The J-extension of the blocked trashrack consisted of 25- and 10-foot panels, 24 ft wide. The J-occlusion assemblies were raised and lowered with hydraulic winches.

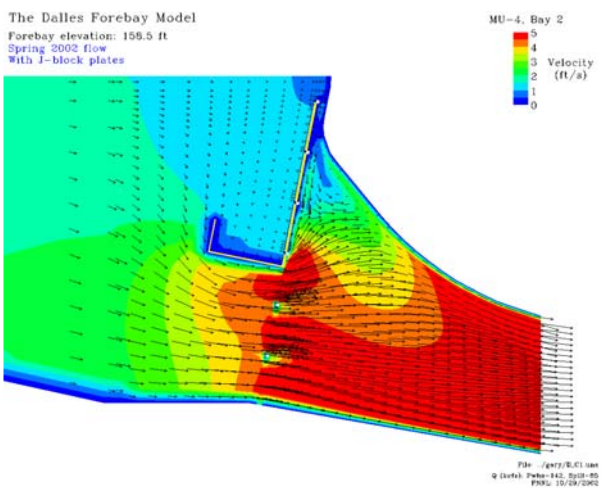
Flow into turbine intakes at The Dalles Dam was slower and flatter with the J-occlusions OUT than IN (Figure 2.3). With the J-occlusions in place, water was drawn downward from the upper water column (El. 120 ft and below) in the forebay above the bottom of the J-extensions. Velocities were 3 to 4 fps around the bottom of the J-extension. Without the J-occlusions, water in this same region went directly toward the intake. Water velocities generally increased downstream of the trashracks.



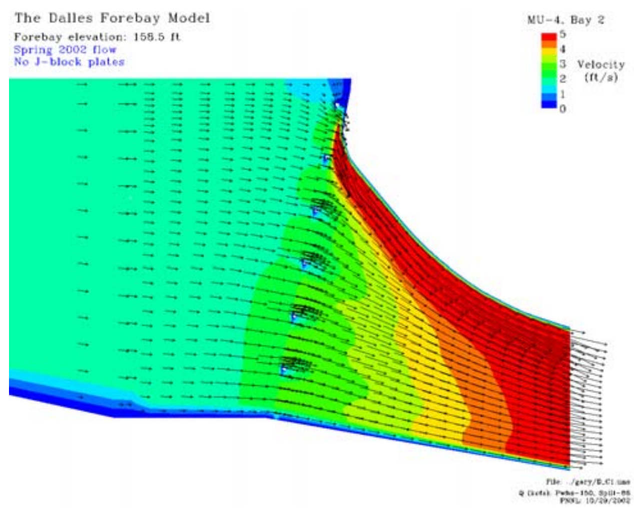
(a) MU 1-2, J-occlusions IN



(b) MU 1-2, J-occlusions OUT



(c) MU 4-2, J-occlusions IN



(d) MU 4-2, J-occlusions OUT

Figure 2.3. Sectional View of Water Velocity at the Centerlines of MU 1-2 and MU 4-2 with J-Occlusions IN and OUT. Data are from a computational fluid dynamics model.

2.4 River Environment and Project Operations

During the study (April 20 to July 12, 2002), daily river discharge at TDA ranged from 170 to 378 kcfs (Figure 2.4). Mean daily discharge was 234 kcfs in spring (April 20 to May 31) and 300 kcfs in summer (June 1 to July 12). Discharge peaked in early June. During the 2002 study, total project discharge was 83% of the 10-year average for spring and 116% of the 10-year average for summer. Daily powerhouse discharge averaged 143 kcfs in spring and 183 kcfs in summer. Spill for fish protection in the "juvenile pattern" (Bays 1-15 only) commenced on April 11. Daily spill flow during our study ranged from 69 to 199 kcfs, with a mean of 87 kcfs (37% of total) in spring and 113 kcfs (38% of total) in summer.

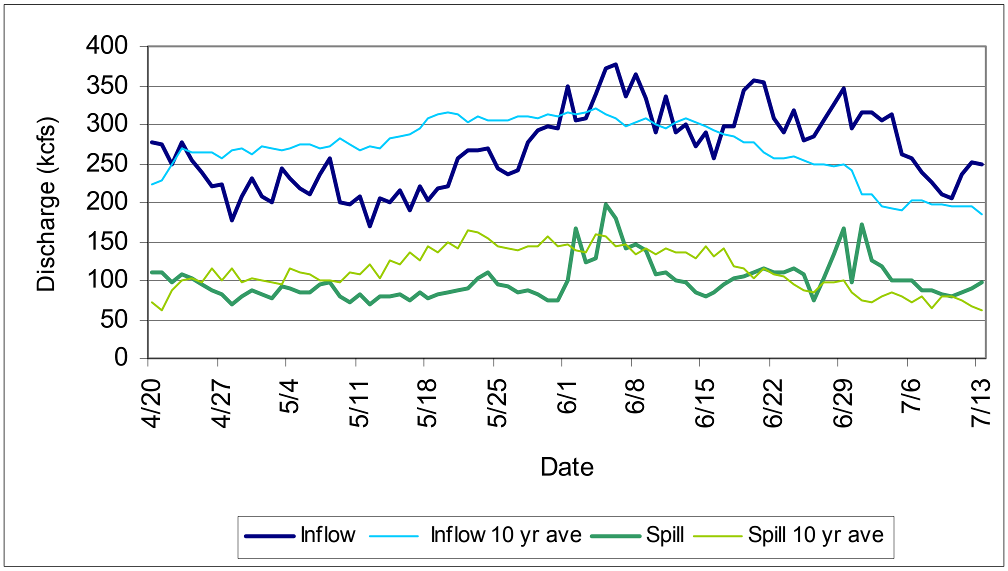
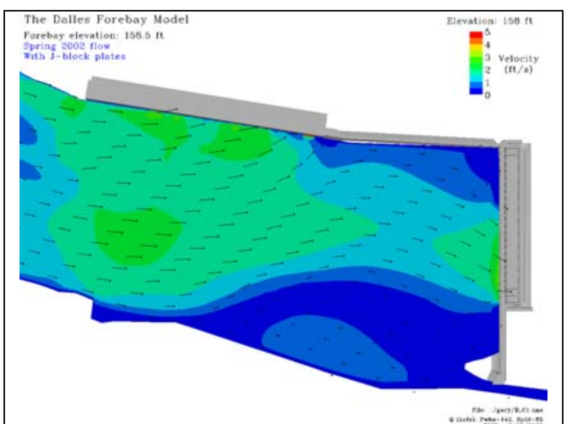


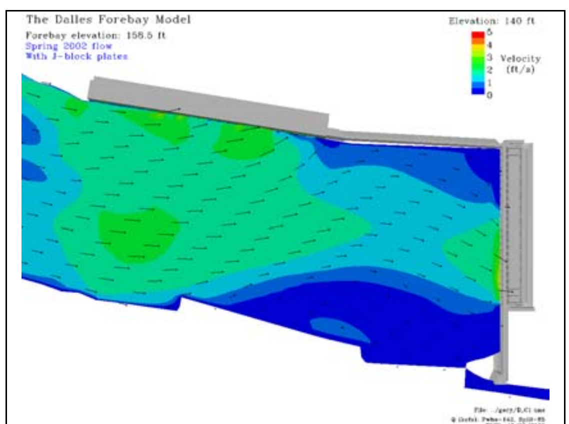
Figure 2.4. Total Outflow and Spill (kcfs) for April 15 – July 31, 2002, at The Dalles Dam. Data were obtained from DART, an Internet website (http://www.cqs.washington.edu/DART/).

Forebay water velocities were 1-3 fps (Figure 2.5). Velocities were higher in summer than spring since the powerhouse and spillway discharges increased from spring to summer. Near the non-overflow wall west of the powerhouse, a null zone of low velocity was more prominent with the J-occlusions OUT than IN. The velocity pattern was similar at El. 140 ft and El. 158 ft.

Forebay elevation during the study ranged from 157.1 ft to 159.0 ft (Figure 2.6). Mean forebay elevation was 158.3 ft in spring and 158.1 ft in summer. With Sluice Gates 1-1, 1-2, and 1-3 fully open and the forebay at elevation 158 ft, sluice discharge is 3,800 cfs (rating curve provided by C. Goodell, Corps of Engineers Portland District, pers. comm.). Thus, sluice discharge was about 1.6% of mean daily discharge for the total project in spring and 1.3% in summer.



(a) Spring, J-Occlusions IN, El. 158



(b) Spring, J-Occlusions IN, El. 140

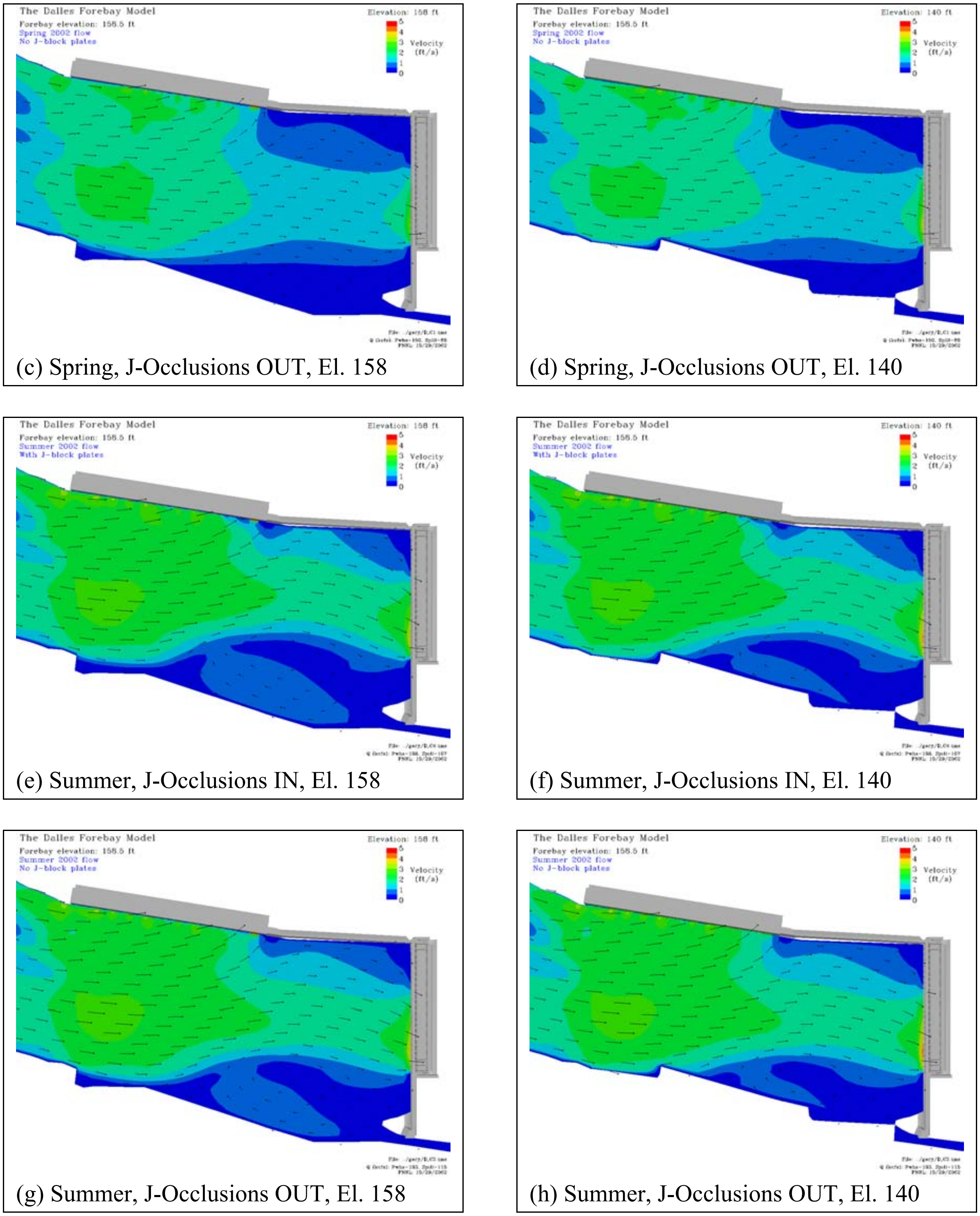


Figure 2.5. Plan View of Forebay Velocity Regime at El. 158 ft (surface) and El. 140 ft with J-Occlusions IN and OUT for Spring and Summer. Spring conditions were 150 kcfs powerhouse and 86 kcfs spillway. Summer flows were 185 kcfs powerhouse and 115 kcfs spillway. In both cases, forebay elevation was 158.5 ft. These were the "average" conditions.

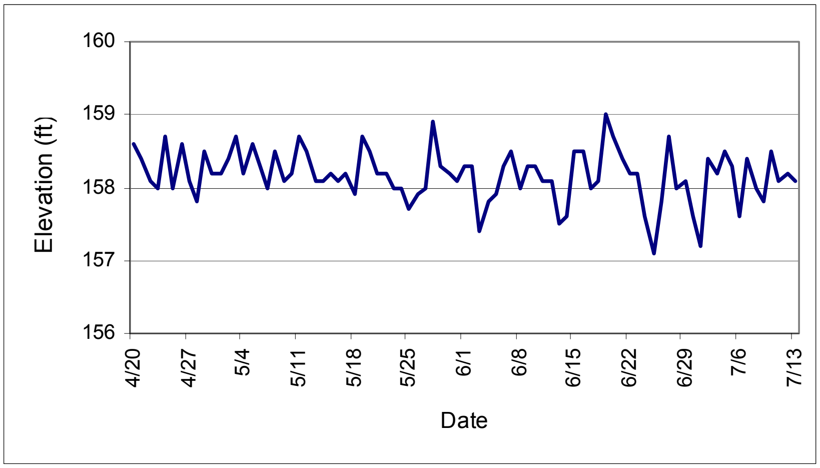


Figure 2.6. Mean Daily Forebay Elevation for April 15 – July 31, 2002, at TDA. Data were obtained from DART, an Internet website (http://www.cqs.Washington.edu/DART/).

Water temperature generally increased as the study progressed (Figure 2.7). It ranged from 10.0 °C to 18.9 °C and was 1.4 °C warmer than the 10-year average in spring and 1.0 °C cooler in summer. Turbidity was generally low, averaging 3.8 secchi-ft (Figure 2.7).

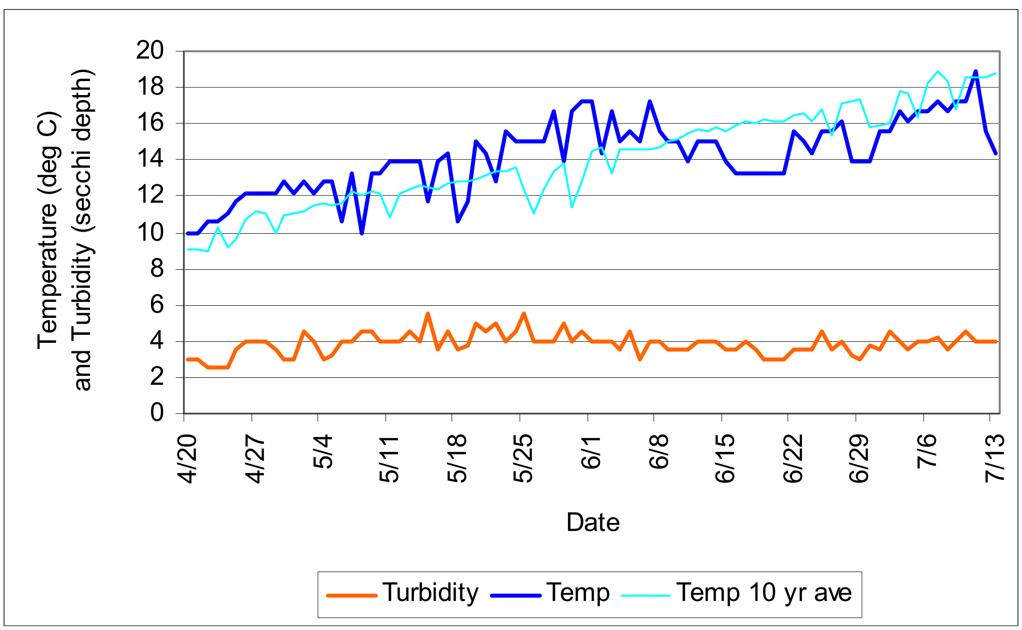


Figure 2.7. Mean Daily Temperature and Turbidity for April 15 – July 31, 2002 at TDA. Data were obtained from DART (http://www.cqs.Washington.edu/DART/).

2.5 Smolt Migration Characteristics

Data on smolt migration characteristics at The Dalles Dam were based on the Smolt Monitoring Program's (SMP) sampling at John Day Dam. This is the closest SMP facility upstream of The Dalles Dam; SMP sampling is not conducted at The Dalles Dam. The data were not lagged because travel times between John Day and The Dalles dams are relatively fast (generally < 1 d, based on radio telemetry data, J. Beeman, USGS Biological Resources Division, pers. comm.).

Our study encompassed most of the migrations of yearling (stream-type) chinook (*Oncorhyncus tshawytscha)*, coho (*O. kisutch*), and sockeye (*O. nerka*) salmon and steelhead (*O. mykiss*), and subyearling (ocean-type) chinook salmon (Figure 2.8). Passage of yearling fish peaked in mid- to late May (Figure 2.8). Passage of subyearling chinook, the most abundant salmonid fish migrating downstream through John Day Dam, peaked at the end of June. During the spring study period (April 20 to May 31), yearling chinook (57%) were the most abundant juvenile salmonid, followed by sockeye (25%), steelhead (13%), and coho (5%). During the summer study period (June 1 to July 12), subyearling chinook salmon comprised 81% of the outmigration.

The sockeye emigration was noteworthy because it was the largest in the last five years. For the period April 10 to June 30 at John Day Dam's smolt monitoring facility, sockeye comprised the following proportions out of the total passage index: 2002 at 0.16; 2001 at 0.06; 2000 at 0.02; 1999 at 0.08; 1998 at 0.12; and 1997 at 0.02. This pattern was also evident at the McNary Dam smolt sampling facility. Average daily mean length of the juvenile sockeye, as sampled at the John Day Dam facility from April 21 to June 22, 2002, was 104 mm.

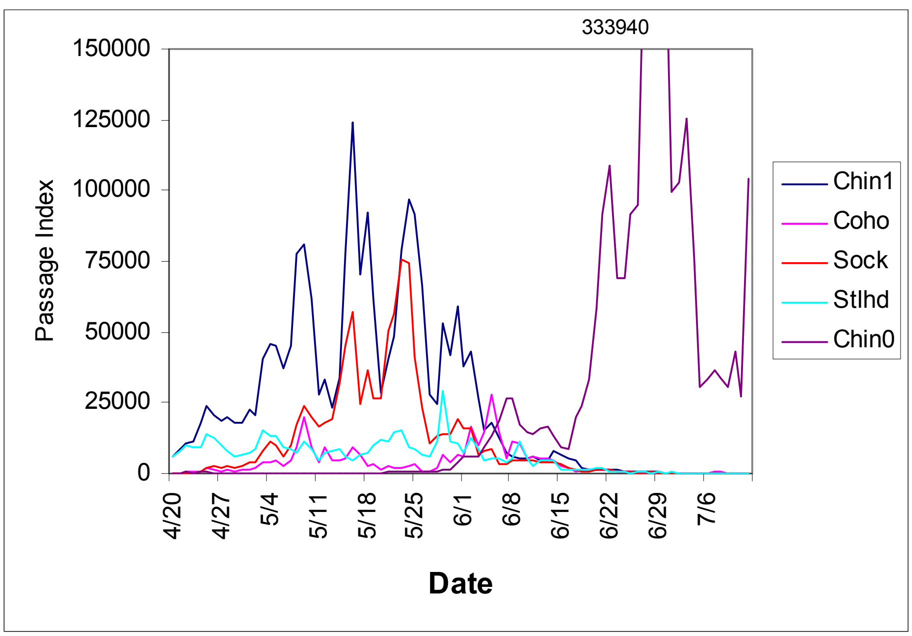


Figure 2.8. SMP Index for April 15 – July 31, 2002, from John Day Dam. Designations in the legend are for subyearling chinook salmon (Chin0), yearling chinook salmon (Chin1), coho salmon (Coho), sockeye salmon (Sock), and steelhead (Stlhd). Data were obtained from DART (http://www.cqs.Washington.edu/DART/).

3.0 Methods

This chapter begins with a description of the experimental design (3.1) followed by a discussion of hydroacoustic methods used (3.2). Objectives 1 through 6 were met using the fixed-location hydroacoustic methods for fish passage and J-occlusion statistical assessment described in Sections 3.2.1 through 3.2.3. Objectives 7 and 8 were met using the sonar tracker and pier-nose split beam methods for tracking fish movements relative to the J-occlusions described in Section 3.2.4. Objective 9 was met with the methods for acoustic camera observations of predator assessment described in Section 3.2.5. Hourly dam operations data were obtained from project operators every 24 h or so during the field work and entered into a database.

3.1 Experimental Design

A randomized block experimental design with two treatments was enacted (Table 3.1). The treatments were for MU 1-4 with J-occlusions deployed (IN) and J-occlusions removed (OUT). A given treatment was in place for three consecutive days. Thus, a block lasted six days. There were seven blocks in the spring period (April 20 to May 31) and seven blocks in the summer period (June 1 to July 12). Treatment days started at 0800 h. On change days, the conversion from one treatment to the other occurred between 0800 h and 1200 h. Project operators implemented the experimental design exactly as planned.

Table 3.1. Randomized Block Experimental Design Treatment Schedule

Spring			Summer		
Block	Dates	Treatment	Block	Dates	Treatment
1	4/20-4/22	IN	8	6/1-6/3	OUT
	4/23-4/25	OUT		6/4-6/6	IN
2	4/26-4/28	IN	9	6/7-6/9	IN
	4/29-5/1	OUT		6/10-6/12	OUT
3	5/2-5/4	OUT	10	6/13-6/15	IN
	5/5-5/7	IN		6/16-6/18	OUT
4	5/8-5/10	IN	11	6/19-6/21	OUT
	5/11-5/13	OUT		6/22-6/24	IN
5	5/14-5/16	IN	12	6/25-6/27	OUT
	5/17-5/19	OUT		6/28-6/30	IN
6	5/20-5/22	OUT	13	7/1-7/3	OUT
	5/23-5/25	IN		7/4-7/6	IN
7	5/26-5/28	OUT	14	7/7-7/9	OUT
	5/29-5/31	IN		7/10-7/12	IN

For statistical reasons, specific turbine operations were critical to the soundness of the 2002 J-occlusion evaluation. Turbine priority from highest to lowest was west to east (MU 1 to MU 22). MU 1-5 were block loaded (discharge held constant) as much as possible and, when load had to vary, load at these units was varied together. Overall, discharge at MU 1-5 was very consistent between treatments (Table 3.2), meaning that differential discharge between treatments did not confound study results.

Table 3.2. Mean Turbine Discharge (kcfs) at MU 1-5 for J-Occlusions IN and OUT during Spring and Summer Study Periods

		MU1	MU2	MU3	MU4	MU5	Mean
Spring	IN	13.4	13.6	12.9	13.5	13.6	13.4
	OUT	13.6	13.7	13.0	13.7	13.8	13.5
Summer	IN	13.8	13.8	13.5	13.8	13.9	13.7
	OUT	13.7	13.8	13.4	13.7	13.9	13.7

3.2 Fixed-Location Hydroacoustic Methods

We applied fixed-location hydroacoustics to address Objectives 1-6, the passage characterizations and J-occlusion comparisons. This technique, conceived by Carlson et al. (1981) for single-beam acoustic systems, is described by Thorne and Johnson (1992). In addition to single-beam, split-beam technology is now an important element of fixed-location hydroacoustics. Split-beam is explained by MacLennan and Simmonds (1992). The methods used in 2002 were similar to those employed in the 2001 hydroacoustic study at The Dalles Dam (Moursund et al. 2002).

The general approach used a combination of 6° single-beam and 6° split-beam transducers deployed to estimate fish passage rates and distributions by applying the acoustic screen model to determine passage rates. Split-beam transducers provided data to determine weighting factors, assess assumptions of the model, and determine the magnitude of any biases. Split-beam transducer deployments at each type of passage route were used to estimate the average backscattering cross section of fish for detectability modeling and the direction of fish travel through sampling volumes to assess the assumptions of the acoustic screen model. Single and split-beam transducers were deployed to sample fish passage at the spillway, sluiceway, and turbines. Transducer sampling volumes were strategically aimed to minimize ambiguity in ultimate fish passage routes and the potential for multiple detections of the same fish.

3.2.1 Data Collection

3.2.1.1 Hydroacoustic Systems

Single-beam data collection involved five Precision Acoustic Systems (PAS) single-beam multiplexed systems. Split-beam data collection included two PAS split-beam systems. All systems operated at 420 kHz. The single-beam data collection system consisted of Harp-1B Single-Beam Data Acquisition/Signal Processing Software installed on a personal computer controlling a PAS-103 Multi-

Mode Scientific Sounder. The PAS-103 Sounder then operated a PAS 420 kHz single-beam transducer deployed in a main turbine unit, fish unit, or spill bay.

3.2.1.2 Transducer Locations and Orientations

In total, 50 transducers were deployed at the powerhouse, sluiceway, and spillway (Table 3.3). All sampling locations had single-beam transducers except for MU 2, Sluice 1-1, 1-2, and 1-3, and Spill Bays 2 and 4, which had split-beam transducers. At all main unit intake sampling locations, divers mounted transducers on the bottom trashrack at elevation 65 ft and aimed them upward and downstream toward the intake ceiling at a 25° angle to the plane of the trashrack (Figure 3.1). The uplooking transducers at MU 1-4 sampled fish passage when the J-occlusions were OUT. At prescribed intakes of the fish units and MU 1-4, divers mounted transducers on the inside of the top trash racks at an elevation of 135 feet and aimed them downstream toward the intake floor at a 15° angle to the plane of the trashrack (Figure 3.1). The downlooking transducers at MU 1-4 sampled fish passage when the J-occlusions were IN. The turbine intakes sampled at a given main unit were chosen randomly.

Table 3.3. Transducer Locations and Sample Coverage

Area	Coverage by Unit	Coverage by Intake	Number	Locations
Fish Units	2 of 2	1 of 2	2	FU 1-2, 2-1
Main Units 1-4[(a)]	4 of 4	2 of 3	16	MU 1-1, 1-2 ,2-1, 2-3, 3-1, 3-2, 4-2, 4-3
Main Units 5-22	12 of 18	1 of 3	13	MU 5-3, 6-1, 7-2, 8-3, 11-2, 12-1, 13-3, 14-1, 15-2[(c)], 16-3, 17-1, 19-2, 21-1
Sluiceway	1 of 1	3 of 3	4	Sluice 1-1, 1-2[(d)], 1-3
Spillway[(b)]	15 of 15	n/a	15	Bays 1-15

(a) Two transducers were deployed at each location (up- and downlookers).

(b) Only 15 spill bays were used, except for a limited amount of time in summer when additional bays were opened.

(c) The transducer cable at 15-2 was lost 1 d after the study started and was not replaced because adjacent units were being sampled.

(d) Sluice 1-2 had two transducers to sample IN and OUT treatments.

At the spillway, transducers were mounted on poles, placed about 3 ft below the surface and aimed downward and downstream (Figure 3.2). At the sluiceway, divers attached transducers to the trashrack at elevation 95 ft and aimed them up the face of the dam to the surface to sample sluice passage when the J-occlusions were OUT (Figure 3.3). Other transducers were placed on the vertical plate of the J-occlusion at elevation 111 ft and aimed up to the surface to sample sluice passage during the IN treatment. In addition we deployed side-looking 3° and 6° transducers at the sluiceway to sample fish over the sill where they are undoubtedly entrained in sluice flow. (As explained in Section 4.1, however, data from the side lookers at the sluiceway were unusable.) At a given sample location, the transducer was randomly placed in one of three horizontal positions (left, middle, or right).

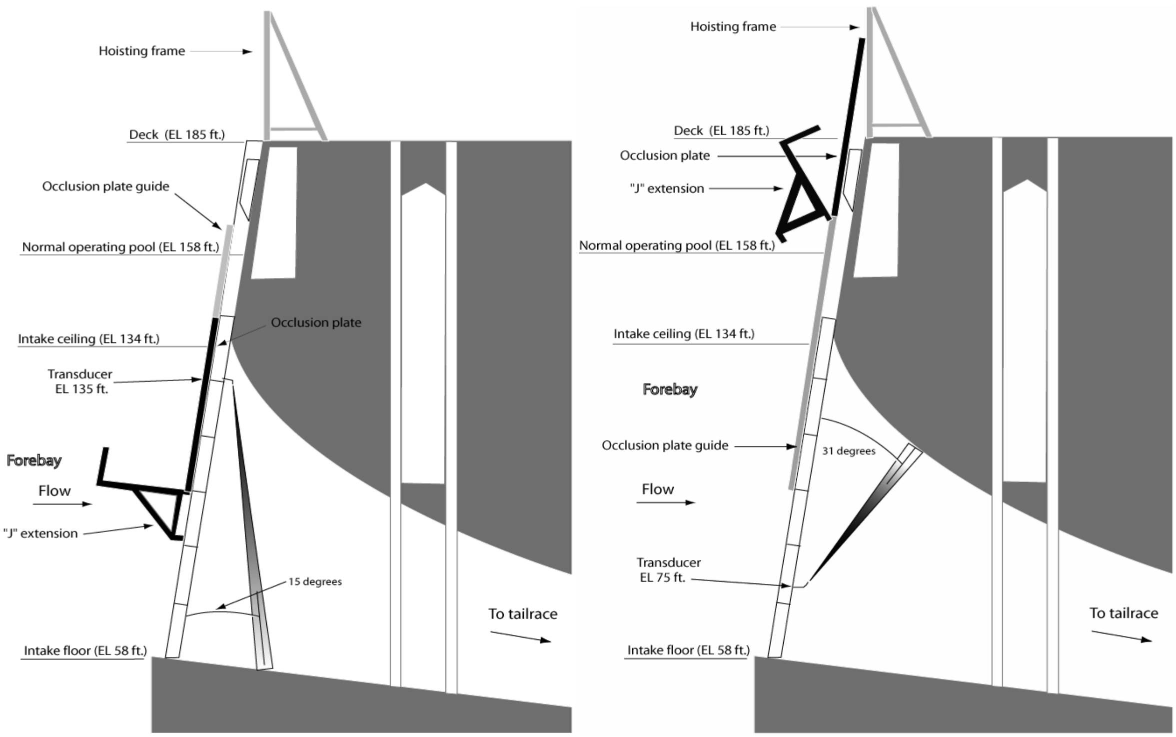


Figure 3.1. Turbine Passage Transducer Deployments for J-Occlusions IN (left) and J-occlusions OUT (right) at MU 1-4. (The up-looking transducer was actually at elevation 65 ft). Fish Units 1 and 2 were occluded for the duration of the study.

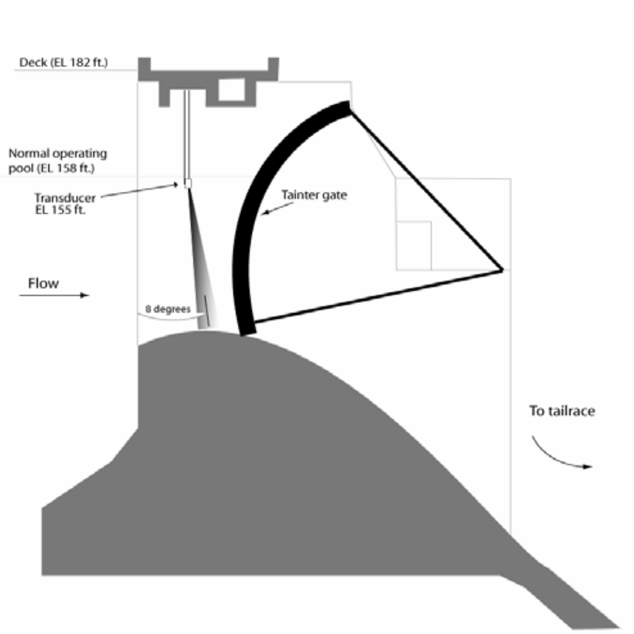


Figure 3.2. Cross-Sectional View of a Spillway Transducer Deployment

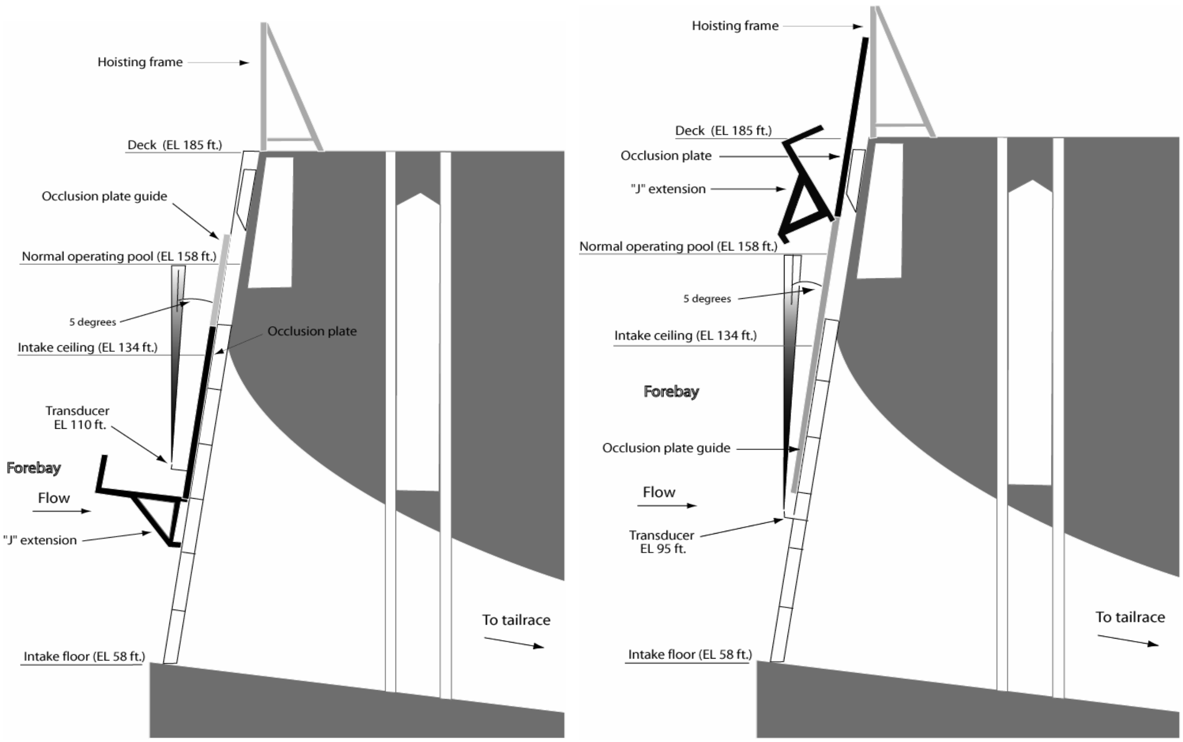


Figure 3.3. Sluiceway Transducer Deployments for J-Occlusions IN (left) and J-Occlusions OUT (right)

3.2.1.3 Sampling Design

Pulse repetition rates were 15 pps (pings per sec) at the turbine intakes, 30 pps at the spillway, and 20 pps at the sluiceway. Systematic samples (same order each hour) were collected at 1-min intervals 24 h/d. Each location was sampled 6 to 10 times per hour.

3.2.2 Data Analysis

3.2.2.1 Data Processing and Reduction

After the acoustic echo data were collected and archived, they were processed to extract fish tracks. At this stage in the analysis, we were careful to set the tracking parameters to not exclude fish at the expense of including spurious tracks. Next, to separate acceptable tracks from unwanted tracks, we filtered using fish tracks characteristics, such as slope and pulse width. This data processing and reduction process was similar to that used by Moursund et al. (2002).

3.2.2.2 Passage Rate Estimation and Performance Metrics

The process to estimate passage rates from tracked fish is explained in detail in Appendix A. Briefly, each fish detection was weighted spatially to account for the sample width of the acoustic beam at the target's mid-range relative to the width of the passage route. The sum of these weighted fish was then extrapolated temporally to account for the fact that only 6-10 min of each hour were sampled. The variances associated with each passage rate estimate were likely underestimates because between-intake variability in passage within a given turbine unit could not be accounted for because of sampling limitations. Ninety-five percent confidence intervals were calculated as follows:

$$CI = \pm 1.96 * \sqrt{Variance}$$

The passage rate data were used to estimate various performance metrics, including fish passage efficiency, spillway efficiency and effectiveness, sluiceway efficiency and effectiveness, and MU 1-4 passage. Equations for each estimator are contained in Appendix A.

3.2.3 Statistical Analysis

To statistically compare J-occlusion IN and OUT treatments, fish passage efficiency, sluiceway efficiency, and MU 1-4 passage were used as response variables in a 2-way (block and treatment) analysis of variance (ANOVA). Separate analyses for day and night periods (day defined as 0600-2000 h in spring and 0600-2100 h in summer) were performed for each metric. The MU 1-4 passage data and the sluice efficiency and fish passage efficiency data were transformed using the natural logarithm or arcsin functions, respectively. Two-tailed statistical tests were employed because the main concern was whether the difference observed in the response variable between the IN and OUT treatments was significant. See Appendix A for more details, including the ANOVA model.

3.2.4 Sonar Tracker and Pier Nose Split-Beam Methods

Sonar trackers and a split-beam transducer were deployed to address Objectives 7 and 8 regarding fish movement relative to the J-occlusions. One sonar tracker was placed on the pier nose between Main Units 4 and 5. It sampled fish movement at the edge of the J-occlusion when it was IN and in the same region during the OUT treatment. The purpose of this deployment was to compare movement patterns between treatments to assess whether there was an edge effect causing abnormally high passage into MU 4 with the J-occlusions IN. (Recall, the occlusion plates at MU 5 were out of the water during the 2002 study.) A second sonar tracker was located on the tip of the J-extension at MU 4-2. It sampled fish movements as they approached the structure. The purpose here was to determine where fish seemed to start a downward trajectory under the J-occlusion toward MU 4. Sonar tracker data processing and analysis were similar to that reported by Hedgepeth et al. (2002). The methods used in 2002 are explained further in Appendix B.

In addition, a split-beam transducer was deployed about 3 ft deep off the pier nose between Main Units 3 and 4. This transducer was used to sample fish distributions with the J-occlusions IN and OUT. The transducer aiming angle was switched between horizontal (~10^{o} off the surface) and vertical (~20^{o} off the plane of the dam) modes according to the randomized block design that was synchronized with the experimental design of the overall J-occlusion evaluation (Table 3.1). Surface turbulence rendered the data from the horizontal aiming unusable. Vertical distributions, however, were estimated and compared between the IN and OUT treatments and between day and night.

3.2.5 Acoustic Camera Methods

An acoustic camera (known as the DIDSON digital imaging sonar) was deployed periodically at several pier noses at the west end of the dam where the J-occlusions were located. The purpose of the acoustic camera work was to assess the presence and distribution of predators near the sluiceway and the J-occlusions (Objective 9). Work in a tank at Battelle's laboratory in Richland, Washington, was used to ground-truth camera images of known predators (Northern pikeminnow, *Ptychocheilus oregonensis*) and salmon smolts. The acoustic camera was also used to examine smolt passage at the gaps in the J-extensions between pier noses. Technicians monitored the camera and used a dual-axis, remotely controlled rotator to follow ("track") targets of interest. The data were recorded and played back in the laboratory for further analysis. See Appendix C for more acoustic camera methods.

4.0 Results of the Fish Passage Evaluation

This section contains the results of the fish passage evaluation including optimization of deployments and passage rate estimation (Objectives 1-3), passage metrics (Objective 4), and fish distributions (Objective 5).

4.1 Optimization of Deployments and Passage Rate Estimation

Objective 1 was to "optimize transducer deployments at sluiceway entrances to sample fish that are committed to passing when detected." In 2001, fish just upstream of the sluice sill observed using the acoustic camera were not necessarily entrained in sluiceway inflow (Moursund et al. 2002). Since this is the region where uplooking transducers sample fish passage into the sluiceway, concern was raised that fish estimates may be biased. Accordingly, as mentioned above in the methods section on fixed-location hydroacoustic transducer location, we deployed special 3^{o} sidelooking transducers on the walls inside sluice entrances at 1-1, 1-2, and 1-3. Fish detected over the sluice sill would be assumed to be entrained. Unfortunately, excessive turbulence at the face of the transducer (Figure 4.1) from eddy shedding off the J-occlusion framework and the transducer mount itself disrupted the acoustic signal, rendering the data unusable. To avoid this problem in future work, the transducer should be mounted on the pier nose and aimed back over the sill.

Figure 4.1. Photograph Looking Down on the Entrance at Sluice 1-1. Side-looking transducers were mounted on the rails of the walls of the entrance.

Objectives 2 and 3 involved valid estimation of passage rates. Objective 2 was to "use one or more split-beam transducer deployments at each passage route to validate the assumptions of the acoustic screen passage model." Objective 3 was to "estimate passage rates of juvenile salmon at each passage route (individual turbines, spill bays, and sluiceway entrances) and relate passage rates to discharge rates." These objectives were met, as explained in the methods section on fixed-location hydroacoustics and shown in the comparison of passage indices for TDA hydroacoustic and the John Day Dam smolt monitoring program (SMP) (Figure 4.2). The indices match reasonably well (correlation coefficient 0.47) except for a peak in the hydroacoustic index on May 31 not reflected in the SMP index, and vice versa for a SMP peak on June 28.

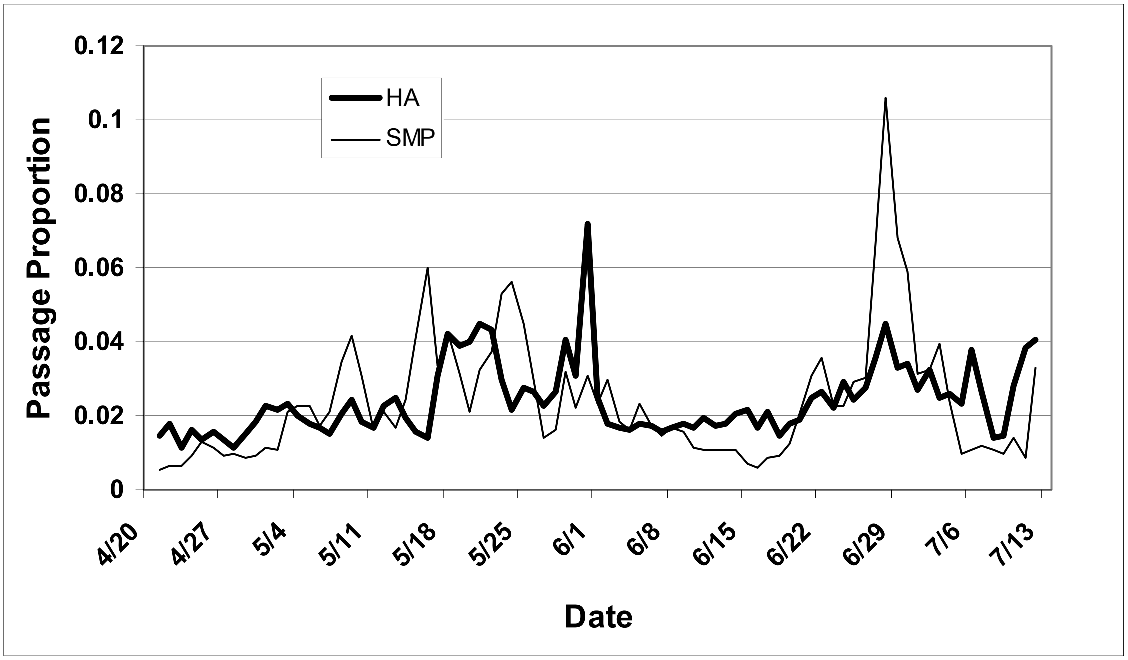


Figure 4.2. Smolt Migration Timing at The Dalles Dam in 2002. Represented by passage indices from hydroacoustic (HA) data from The Dalles Dam and Smolt Monitoring Program (SMP) data from John Day Dam.

4.1.1 Passage Metrics

Objective 4 was to "estimate proportions of fish passing through the spillway, turbines, and sluiceway," i.e., fish passage efficiency, spillway efficiency and effectiveness, and sluiceway efficiency and effectiveness. In this section, we present daily data on fish passage efficiency and spill efficiency, the relationship between spill efficiency and spill level, and summary passage metrics for spring and summer.

Daily fish passage efficiency (FPE; the proportion of non-turbine passage out of total project passage) was variable ranging from 0.30 to 0.84 (Figure 4.3). FPE generally decreased as the study period progressed with efficiencies during the migration of yearling fish in spring somewhat higher than those for subyearling fish in summer (Figure 4.3). A similar trend was reported by Ploskey et al. (2001; 2002).

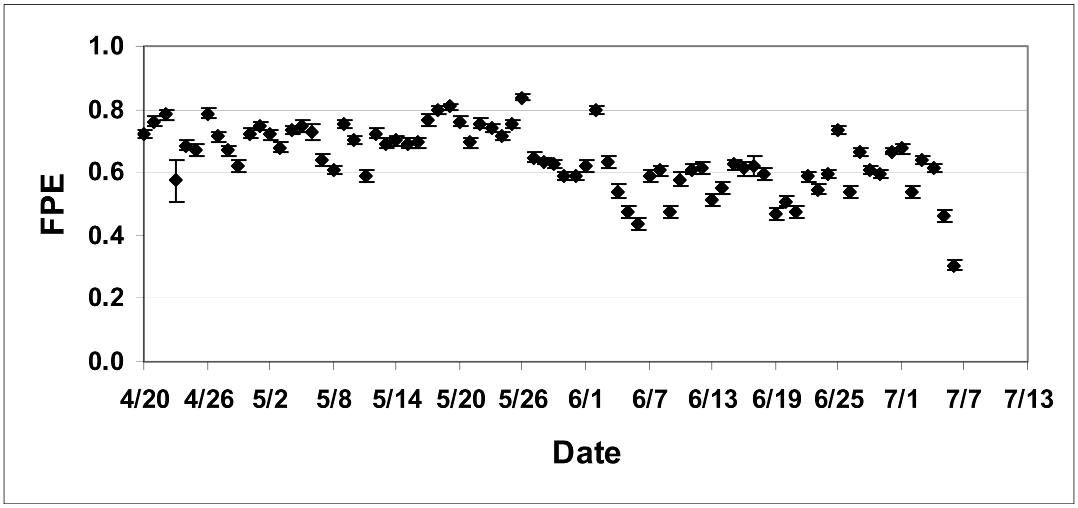


Figure 4.3. Daily Fish Passage Efficiency Estimates with 95% Confidence Intervals for The Dalles Dam in 2002

Daily spill efficiency (the proportion of spillway passage out of total project passage) was highest on April 22 at 0.84 and lowest on May 20 at 0.25 (Figure 4.4). Variation from one day to the next was notable. As with FPE, there was a slight decline in spill efficiency over the study (Figure 4.4).

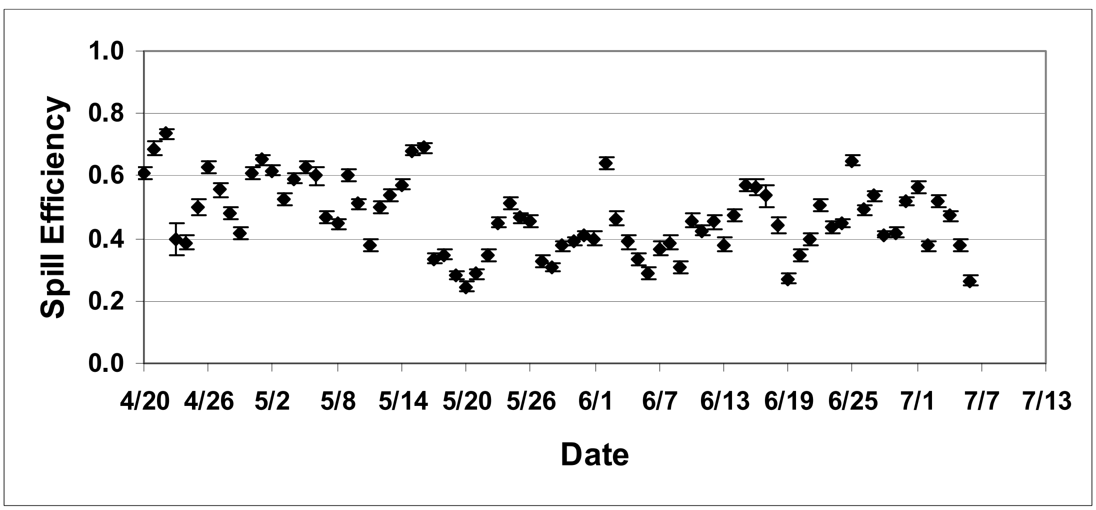


Figure 4.4. Daily Spill Efficiency Estimates with 95% Confidence Intervals for The Dalles Dam in 2002

No trend was evident between spill efficiency and spill level (Figure 4.5). Recall, the spill proportion was reasonably consistent during the study and averaged 37% in both spring and summer.

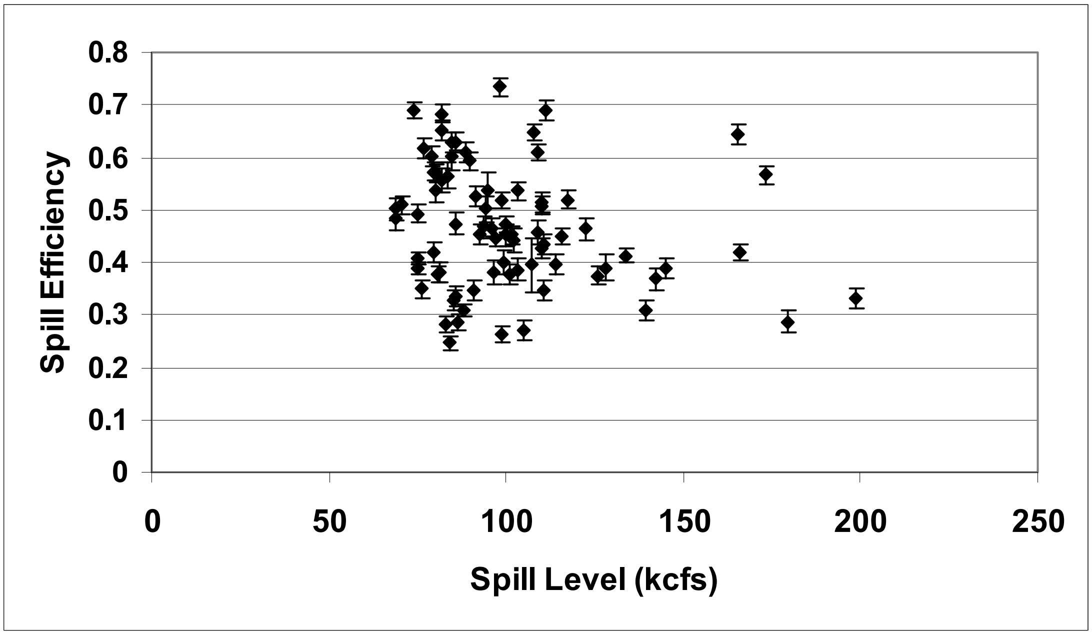


Figure 4.5. Scatterplot of Daily Spill Efficiency with 95% Confidence Intervals vs. Spill Level (kcfs) for the April 20-July 6, 2002, Period

Passage for the run at large can be summarized using overall hydroacoustic passage statistics (Table 4.1). Fish passage efficiency estimates were 0.69 for spring (April 20 to May 31) and 0.50 for summer (June 1 to July 6). Spill efficiency also decreased from spring (0.45) to summer (0.38), as did sluice efficiency (0.25 in spring and 0.11 in summer). Sluice effectiveness (fish:flow ratio for the sluiceway) was over ten times higher than spill effectiveness (fish:flow ratio for the spillway) in spring and over seven times higher in summer (Table 4.1).

Table 4.1. Summary Passage Statistics for the Run at Large at The Dalles Dam in 2002

	Spring	Summer
Fish Passage Efficiency	0.69	0.50
Spill Efficiency	0.45	0.38
Sluice Efficiency	0.25	0.11
Spill Effectiveness	1.22	1.03
Sluice Effectiveness	12.96	7.62

4.2 Fish Distributions

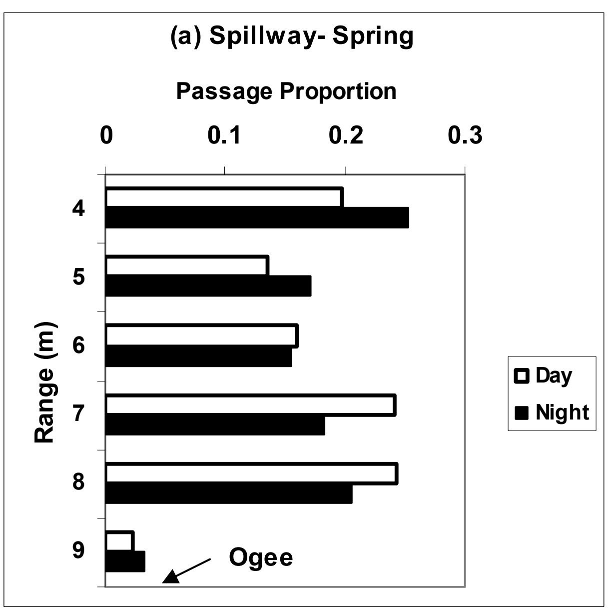
Objective 5 was to "describe the spatial and temporal distributions of fish passage at the powerhouse and spillway," i.e., vertical, horizontal, and diel distributions.

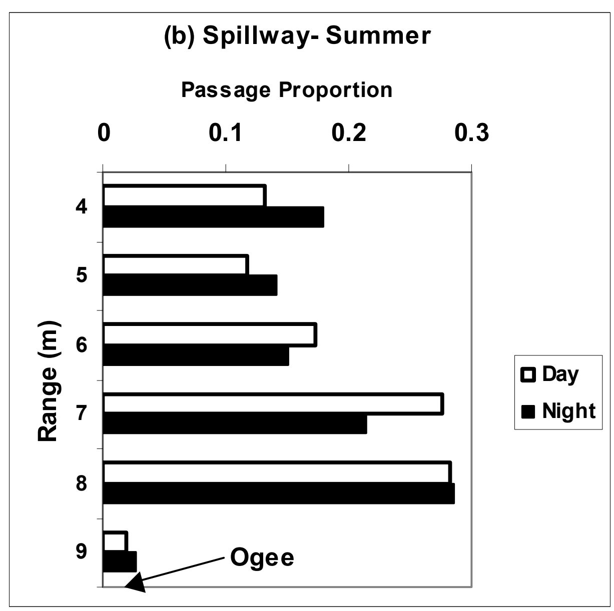
4.2.1 Vertical Distribution

The vertical distribution of smolts was deeper during day than night at all three routes in spring and two of three in summer (Table 4.2 and Figure 4.6). On a seasonal basis, smolts were deeper during summer than spring at the spillway and turbines, but the opposite was true for the sluiceway (Table 4.2). At the spillway, about two-thirds of the fish were detected within 12 ft of the ogee. In turbine, over one-third were within 15 ft of the intake ceiling. Immediately upstream of the sluice sill (entrance), over three-fourths were within 12 ft of the surface; this is a conservative estimate because the surface 3 ft or so are under-sampled because of interference from wind-generated turbulence.

Table 4.2. Summary of Vertical Distributions Expressed as the Proportion within a Given Range Out of Total Passage for the Spillway, Turbines (uplookers), and Sluiceway for Day and Night for Spring and Summer

			Spring		Summer	
Route	Range	Orientation	Day	Night	Day	Night
Spill	w/in 12 ft ogee	Down	0.67	0.58	0.75	0.68
Turbine	w/in 15 ft ceiling	Up	0.33	0.38	0.41	0.39
Sluice	w/in 12 ft surface	Up	0.78	0.85	0.76	0.81





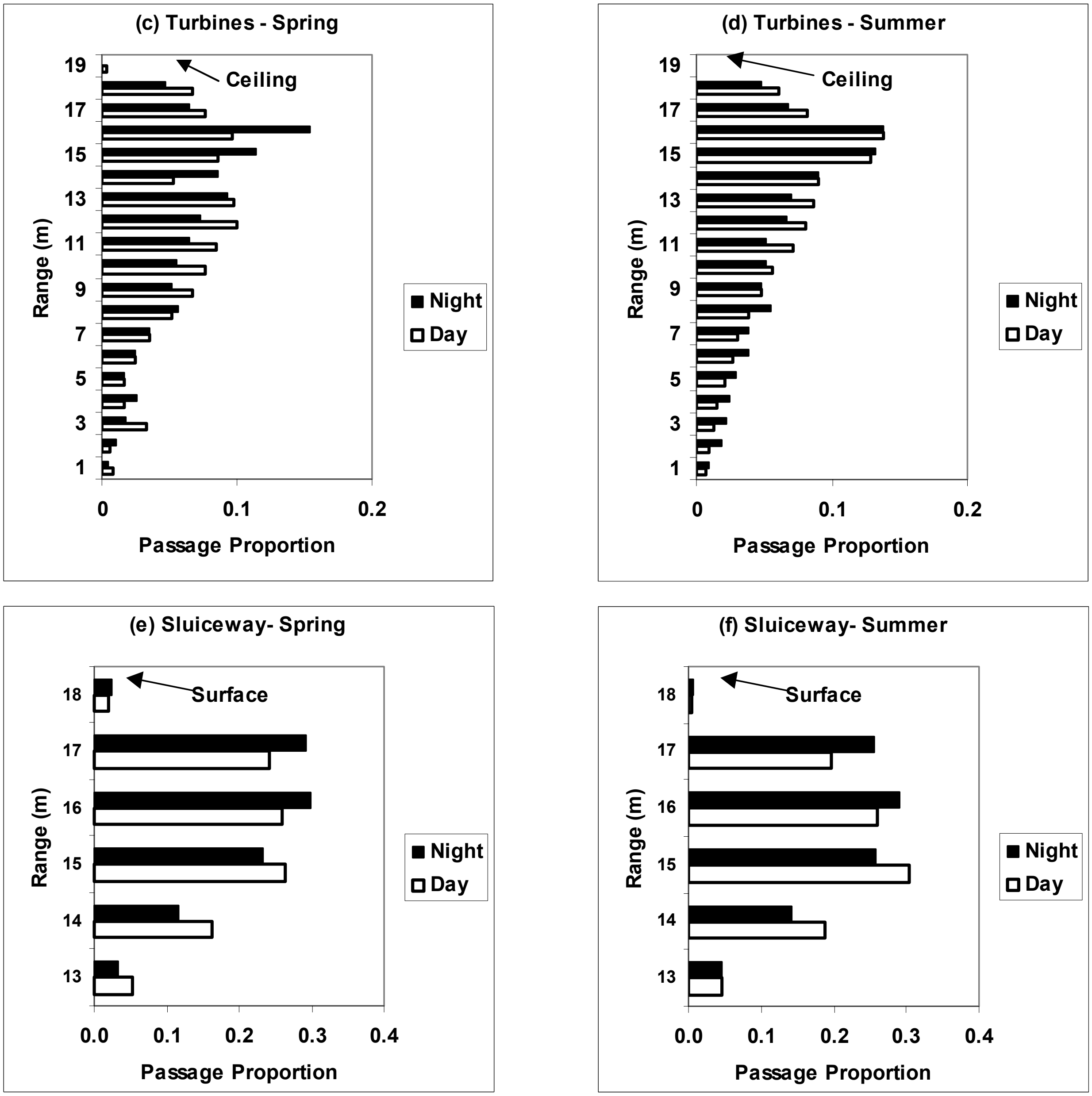


Figure 4.6. Vertical Distributions for the Spillway(a, b), Turbines (uplookers) (c, d), and Sluiceway (e, f)

4.2.2 Horizontal Distribution

The sluice entrances at MU 1 at The Dalles Dam passed more fish than any individual turbine unit (Figure 4.7). The horizontal distribution of fish passage at the powerhouse was skewed to the west (lower numbered units) in spring 2002 (Figure 4.7a). During summer, however, passage was also high at some units in the eastern and middle parts of the powerhouse. Recall, Main Units 10 and 18 were off line in both seasons. Highest passage rates per unit discharge were observed in spring at the western portion of the powerhouse, but in summer highest flow-corrected passage rates were at the eastern portion of the powerhouse (Figure 4.7b). The horizontal distribution of spillway passage was highest toward the middle region of the operating bays (Bays 1-15) with peaks in spring and summer at Bay 11 (Figure 4.7c).

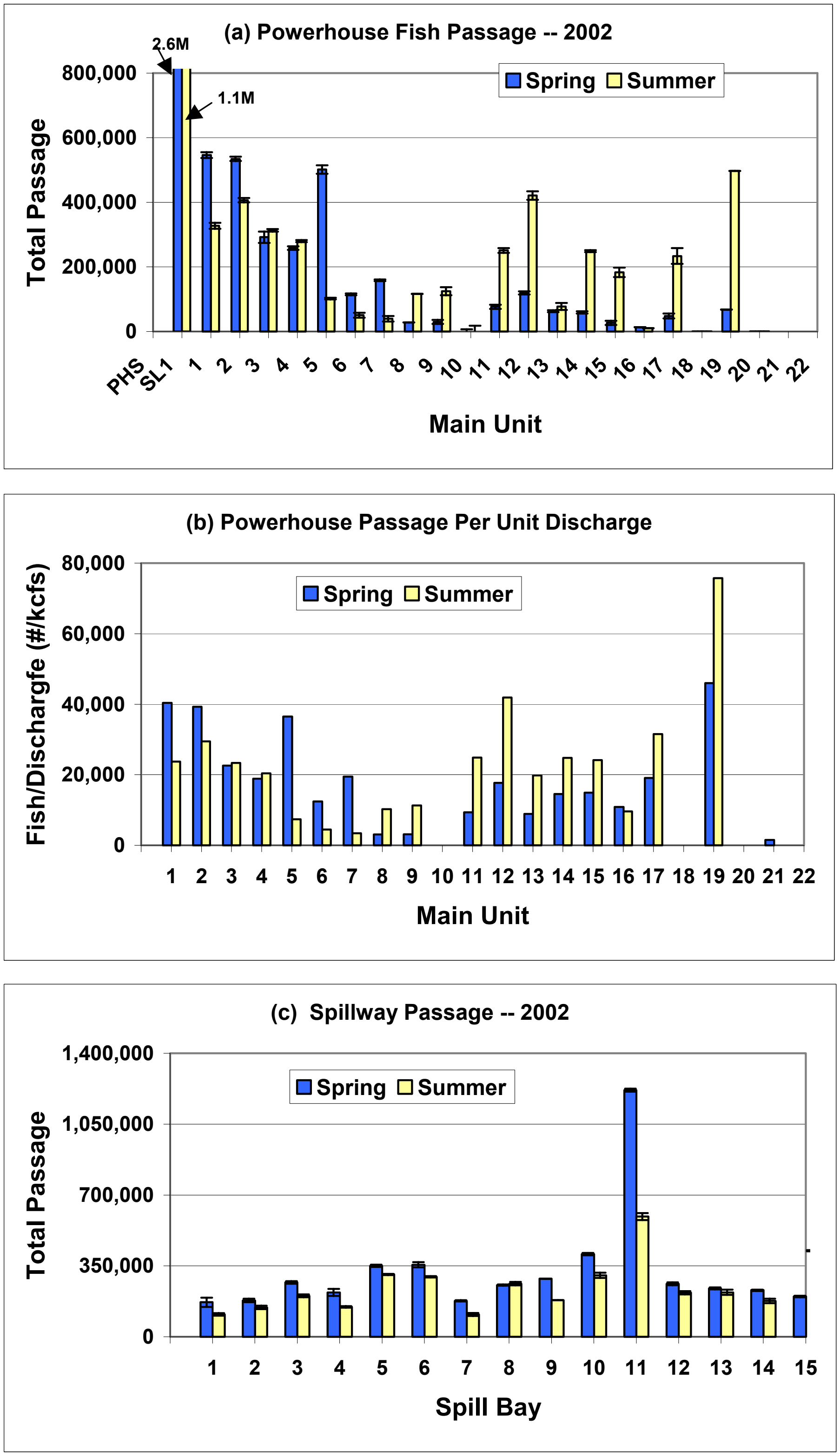


Figure 4.7. Horizontal Distribution of (a) Powerhouse Fish Passage, (b) Powerhouse Passage Per Unit Discharge, and (c) Spillway Passage with 95% Confidence Intervals for Spring and Summer Separately. Sluice passage is included in (a) but not (b) to aid the visualization.

4.2.3 Diel Distributions

Passage at the spillway was higher during day hours than night hours in both spring and summer (Figure 4.8a,b). The usual peak in yearling passage at dusk was evident (Figure 4.8a). Turbine passage was slightly higher during night hours than day (Figure 4.8c,d). Sluiceway passage peaked during the crepuscular periods (Figure 4.8e,f).

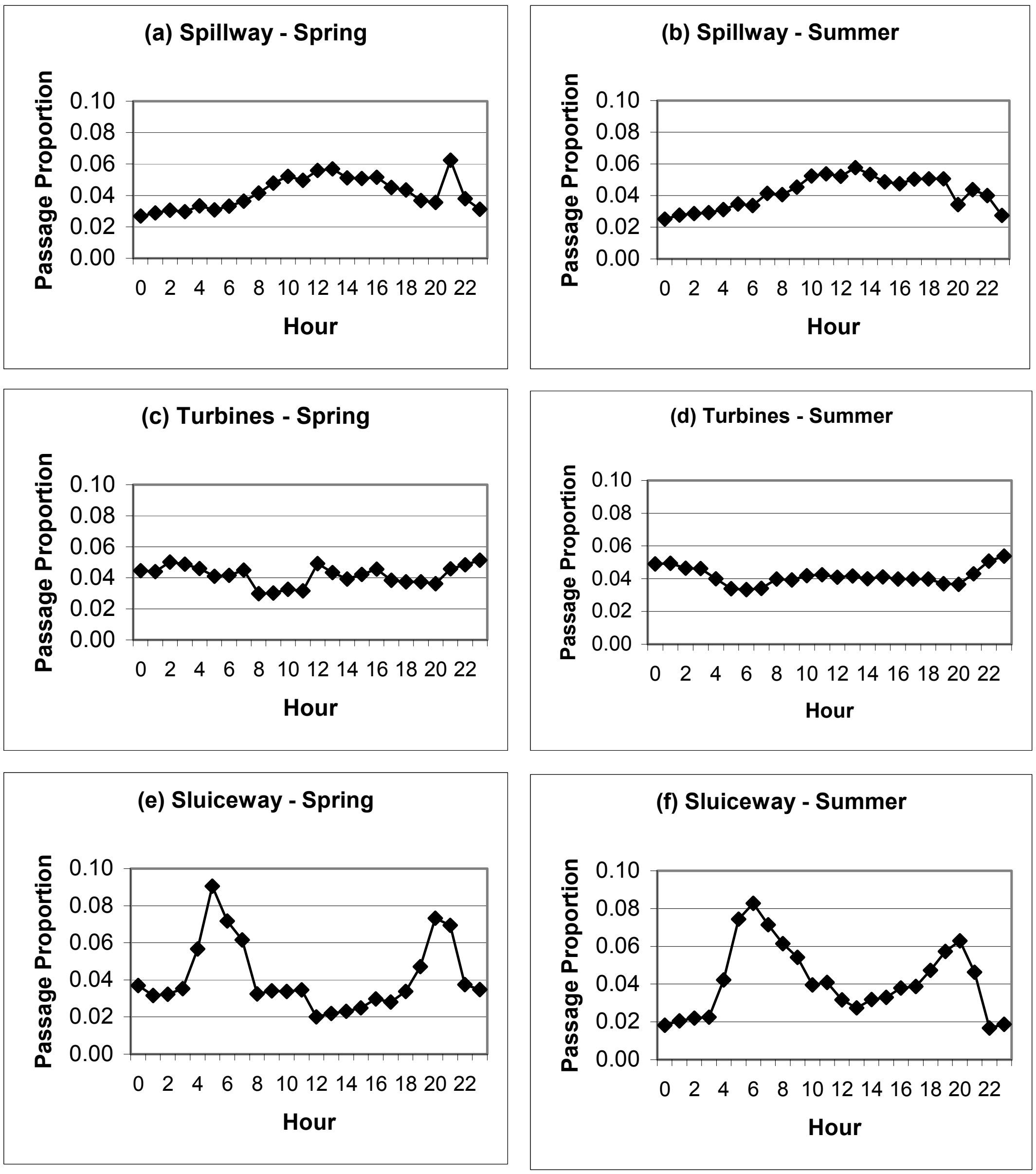


Figure 4.8. Diel Distributions for the Spillway, Turbine, and Sluiceway Passage Routes during Spring and Summer

5.0 Results of the J-Occlusion Evaluation

The J-occlusion evaluation involved statistical analysis of treatment effects (Objective 6), description of fish movements and distributions relative to the J-occlusions (Objectives 7 and 8), and predator abundance around the J-occlusions (Objective 9).

5.1 Analysis of J-Occlusion Performance

Objective 6 was to "assess the effect of the J-block occlusions on fish passage by statistically comparing fish passage metrics, especially passage at MU 1-4, with and without J-block occlusions." In this presentation, we compare data between the two treatments, J-occlusions IN and OUT. Sequentially, we offer daily passage data at MU 1-4, unit by unit passage, and block by block passage with results of the statistical analysis of treatment effects. Data from Block 14 were excluded because numerous adult shad were observed with the acoustic camera in the forebay on July 11.

5.1.1 Daily Passage

Passage at MU 1-4 was one of the main indicators of performance of the J-occlusions. Daily passage at MU 1-4 was relatively uniform except for peaks during May 17-21, June 28-30, and July 5 and 6 (Figure 5.1). The summer peaks coincided with the IN treatment for the most part.

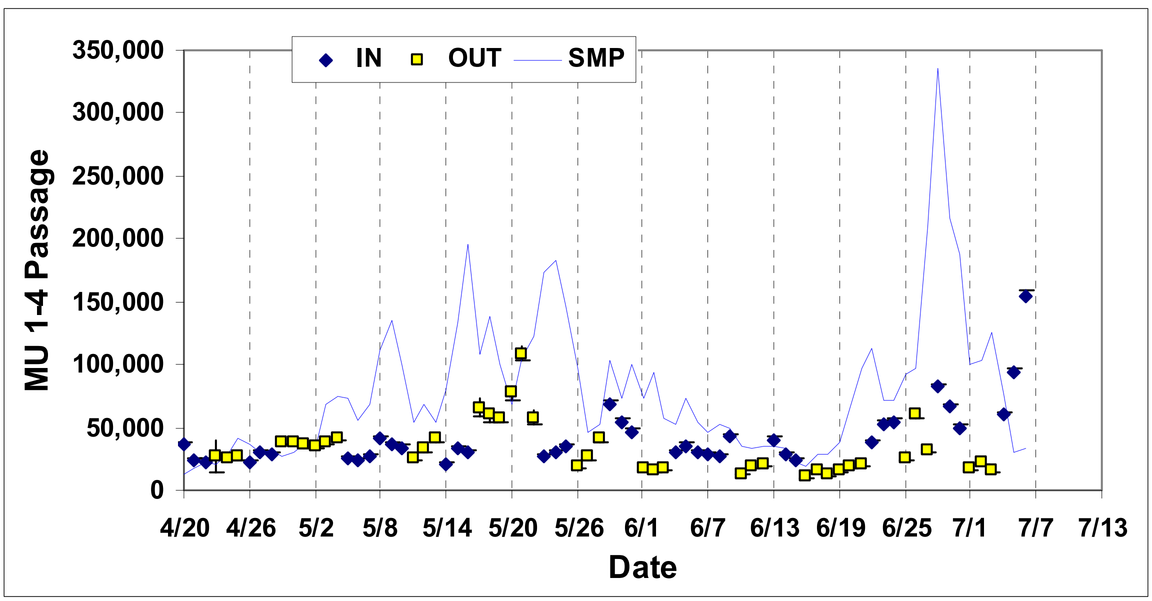


Figure 5.1. Daily MU 1-4 Total Passage with 95% Confidence Intervals and SMP Passage Index for the April 20-July 6 Analysis Period for IN and OUT Treatments. Vertical lines delineate the experimental blocks.

5.1.2 Horizontal Distribution

The horizontal distribution of passage at MU 1-5 for the IN and OUT treatments revealed no consistent trends in spring but it did in summer (Figure 5.2). In spring, the highest passage was observed at MU 2 in the OUT treatment. Passage was generally higher at MU 1 and 2 than it was at MU 3-5. There was no difference between treatment in passage at MU 5 in spring. In summer, passage was uniformly higher at the first four units with J-occlusions when the intakes were occluded than when they were not.

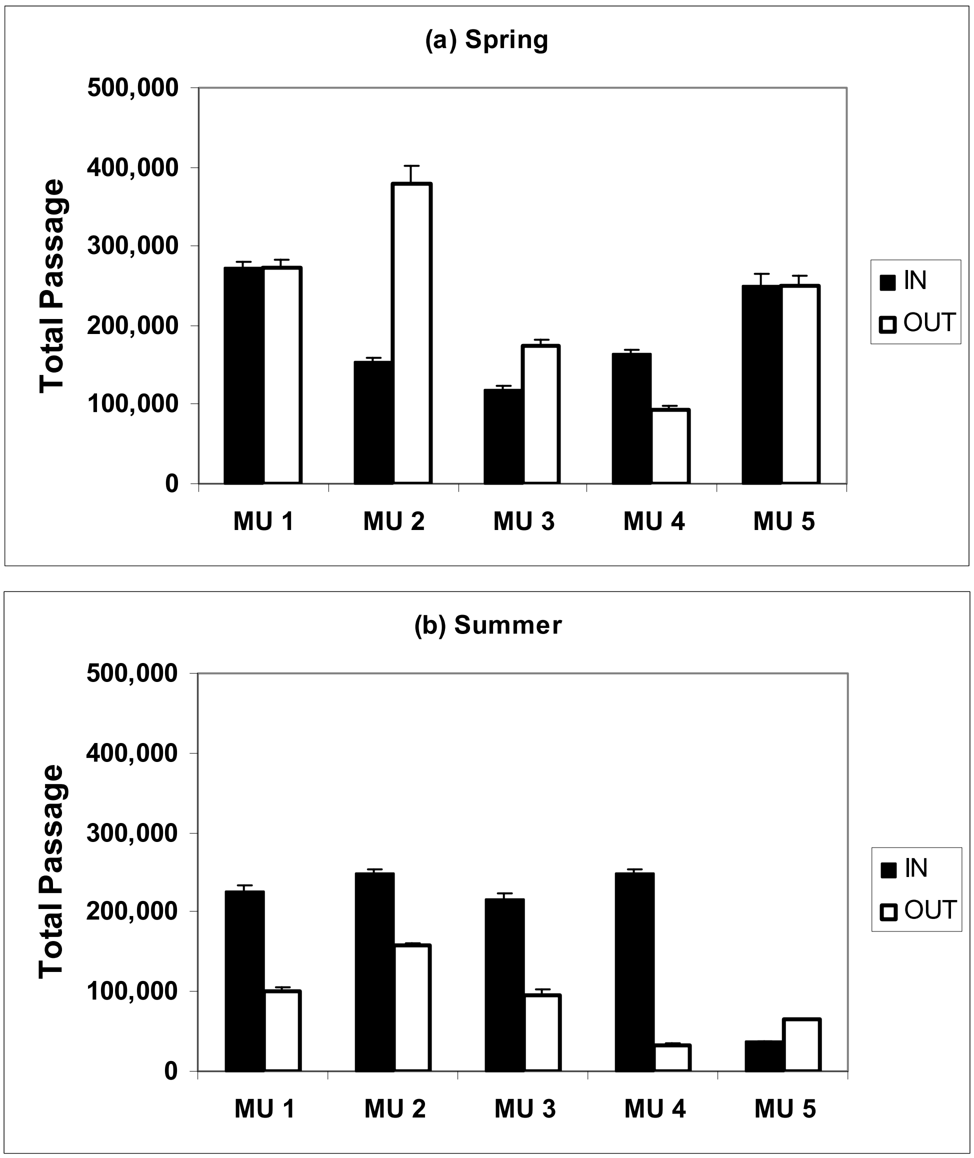
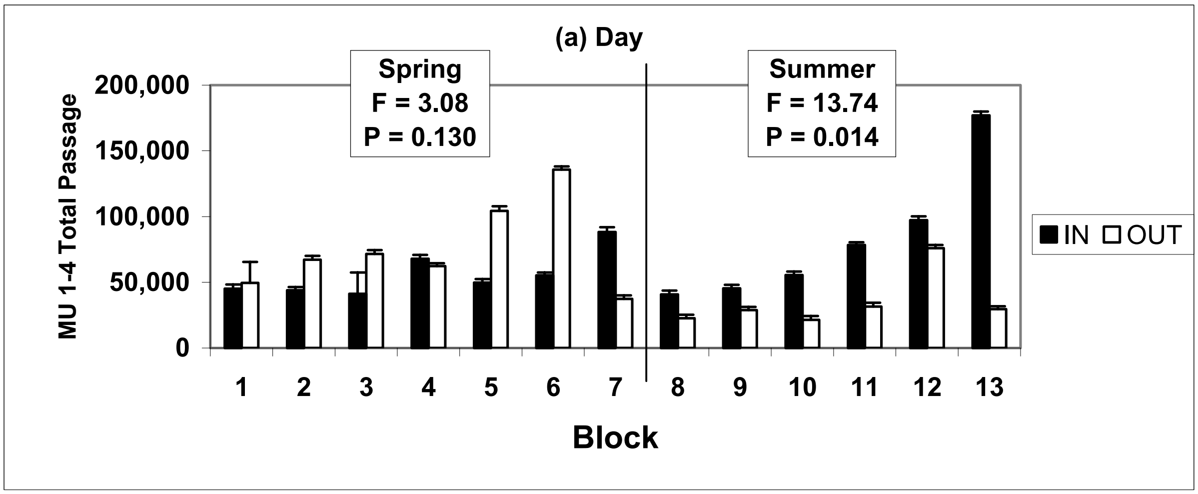


Figure 5.2. Horizontal Distribution of Passage at MU 1-5 with 95% Confidence Intervals for IN and OUT Treatments Separately for Spring (a) and Summer (b)

5.1.3 Passage by Block

Daytime passage at MU 1-4 was greater during the IN treatment than the OUT in 2 of 7 blocks in spring and 6 of 6 blocks in summer (Figure 5.3a). MU 1-4 passage in daytime was significantly different between treatments with the J-occlusions IN and OUT during summer (P=0.014) but not during spring (P=0.13). During nighttime, MU 1-4 passage was significantly different between treatments during both spring (P=0.027), when MU 1-4 passage rates were highest with the J-occlusions OUT, and summer (P=0.002), when MU 1-4 passage rates were highest with the J-occlusions IN (Figure 5.3b).



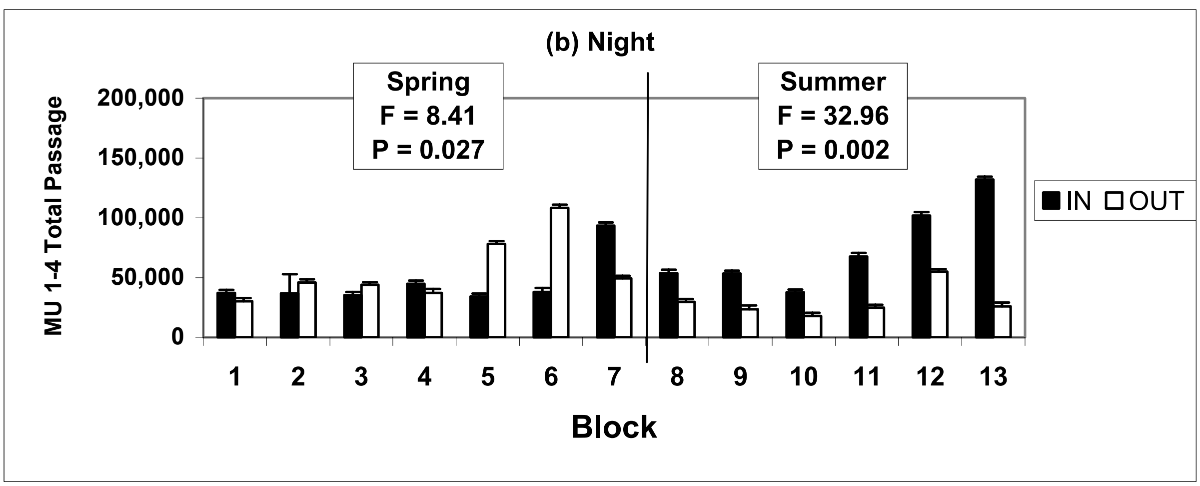


Figure 5.3. Total Passage at MU 1-4 with 95% Confidence Intervals for IN and OUT Treatments for the 13 Usable Blocks (April 20-July 6) for Day and Night Separately. F- and P-values ($\alpha = 0.05$) for the J-occlusion comparison from the ANOVA are provided for spring and summer.

During day, sluiceway efficiency relative to MU 1-4 was greater during the IN treatment than the OUT in 2 of 7 blocks in spring and 1 of 6 blocks in summer (Figure 5.4a). A similar pattern was evident for night (Figure 5.4b). The differences in sluice efficiency between J-occlusions IN and OUT, however, were not significant at the 95% confidence level (Figure 5.4).

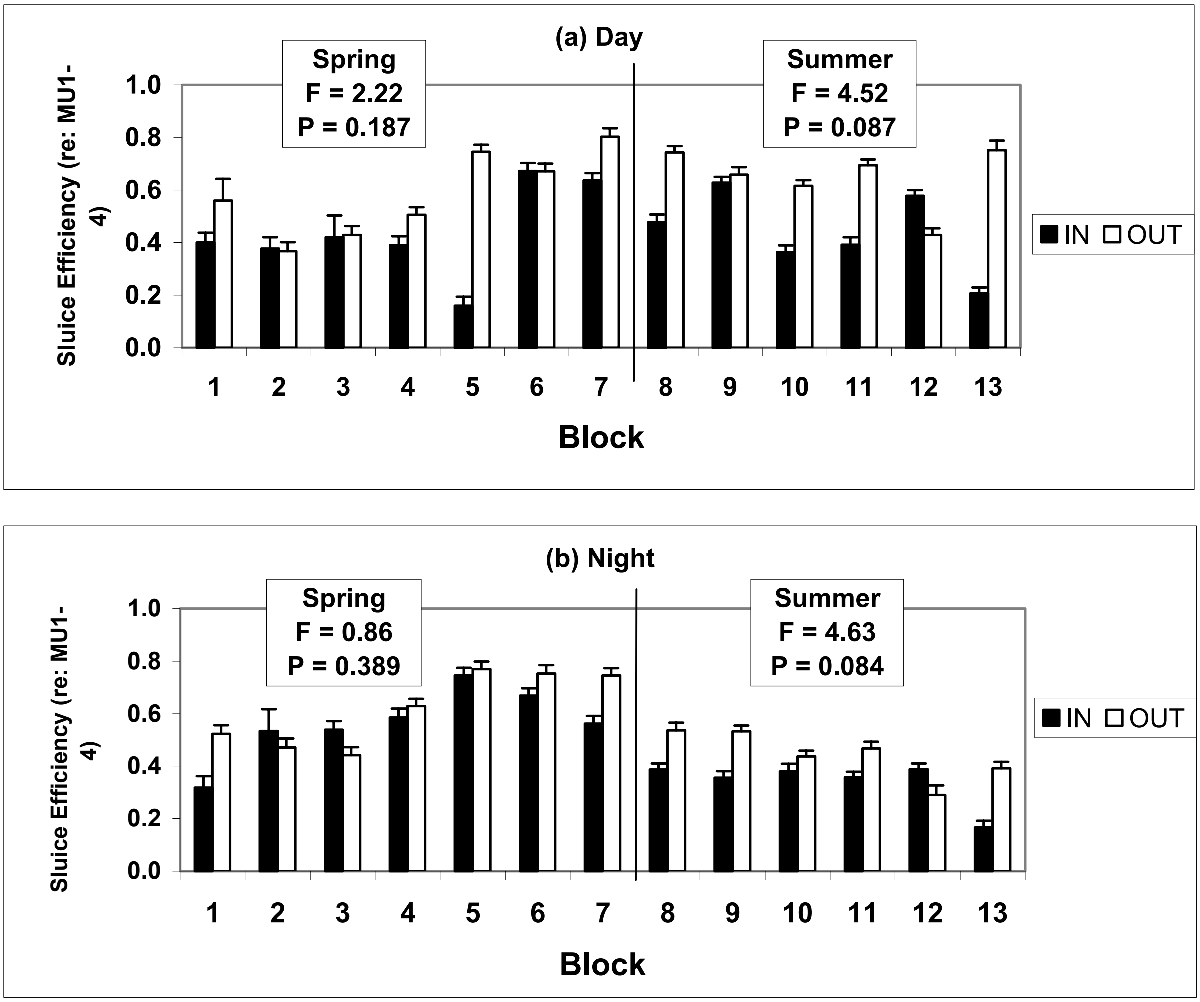


Figure 5.4. Sluiceway Efficiency Relative to MU 1-4 with 95% Confidence Intervals for IN and OUT Treatments for the 13 Usable Blocks (April 20-July 6) for Day and Night Separately. F- and P-values ($\alpha = 0.05$) for the J-occlusion comparison from the ANOVA are provided for spring and summer.

During day, fish passage efficiency for the project as a whole was greater during the IN treatment than the OUT in 5 of 7 blocks in spring and 3 of 6 blocks in summer (Figure 5.5a). A similar pattern was evident for night (Figure 5.5b). Like sluice efficiency, differences in FPE between J-occlusions IN and OUT were not significant (Figure 5.5).

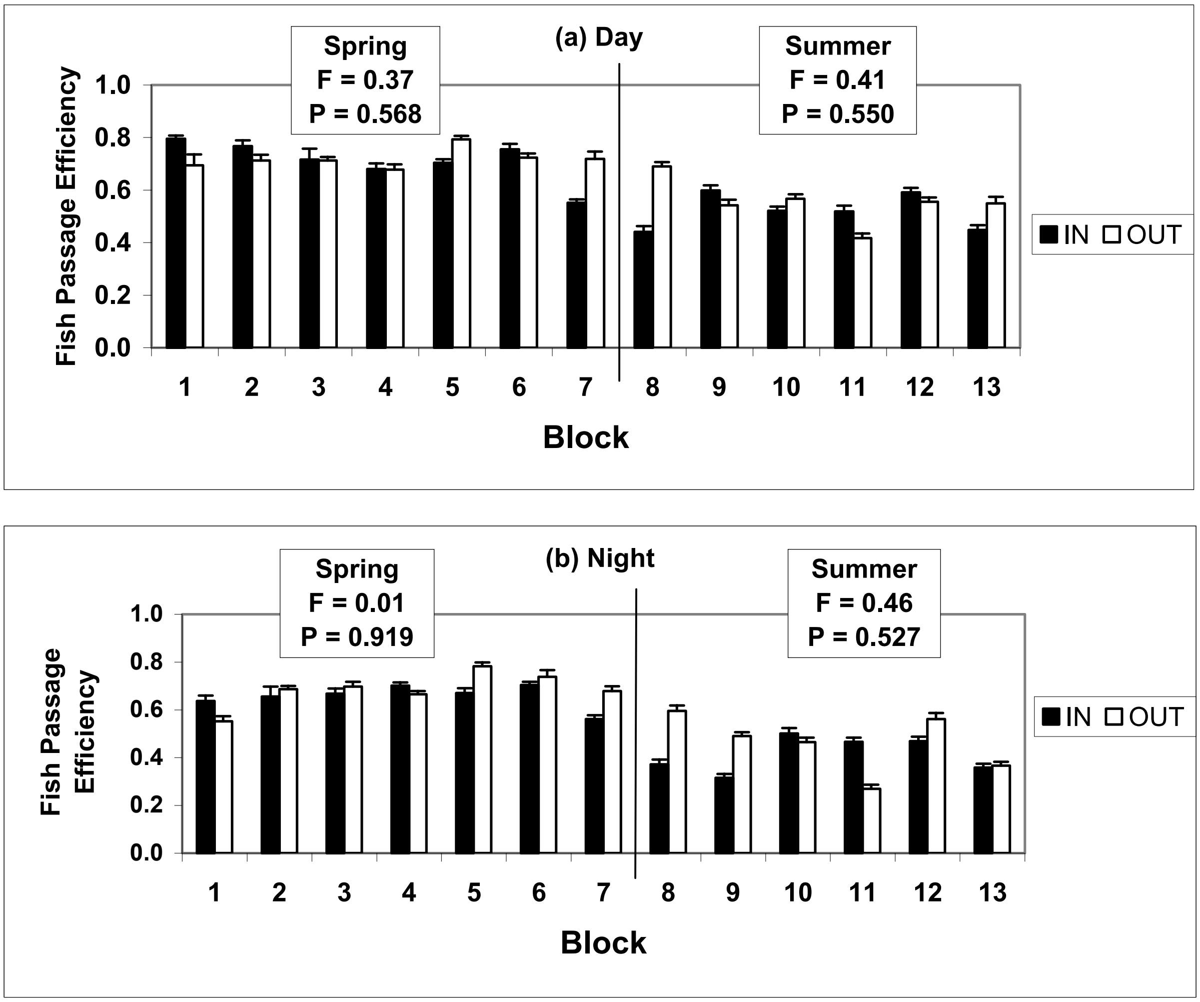


Figure 5.5. Fish Passage Efficiency with 95% Confidence Intervals for IN and OUT Treatments for the 13 Usable Blocks (April 20-July 6) for Day and Night Separately. F- and P-values ($\alpha = 0.05$) for the J-occlusion comparison from the ANOVA are provided for spring and summer.

5.2 Fish Movement and Distribution

This section addresses Objectives 7 and 8. Objective 7 was to "assess potential 'edge effects' at the piernose between MU 4 and 5 relative to J-block occlusions by evaluating differences in turbine passage, fish density, and/or fish movement patterns at MU 4/5 during J-block occlusion treatments." Objective 8 was to "describe fish movement and vertical distribution patterns in front of MU 4 with and without J-block occlusions."

5.2.1 Fish Velocity Vectors

Figures 5.6 and 5.7 show that planar velocity components at the J-occlusion at the second intake of MU 4 (MU 4-2) are noticeably different in the volume above the level of the J-occlusion extension than below it. Figure 5.6 shows that near the surface velocity streamtraces are relatively smooth and uniform with a slight downward and a strong negative X or westward component. Closer to the extension edge the stream traces become more erratic and velocities are higher downstream. A stronger negative Z or downward component in the lower depths is noted in the slice further from the dam. The 7-m-deep slice in Figure 5.7 shows that fish farther from the dam approach it more strongly. As they approach the dam, they decrease their approach and become nearly parallel to it. Slices deeper than the top of the J-extension show a strong toward-dam component during the day and night with some off-dam vectors at night.

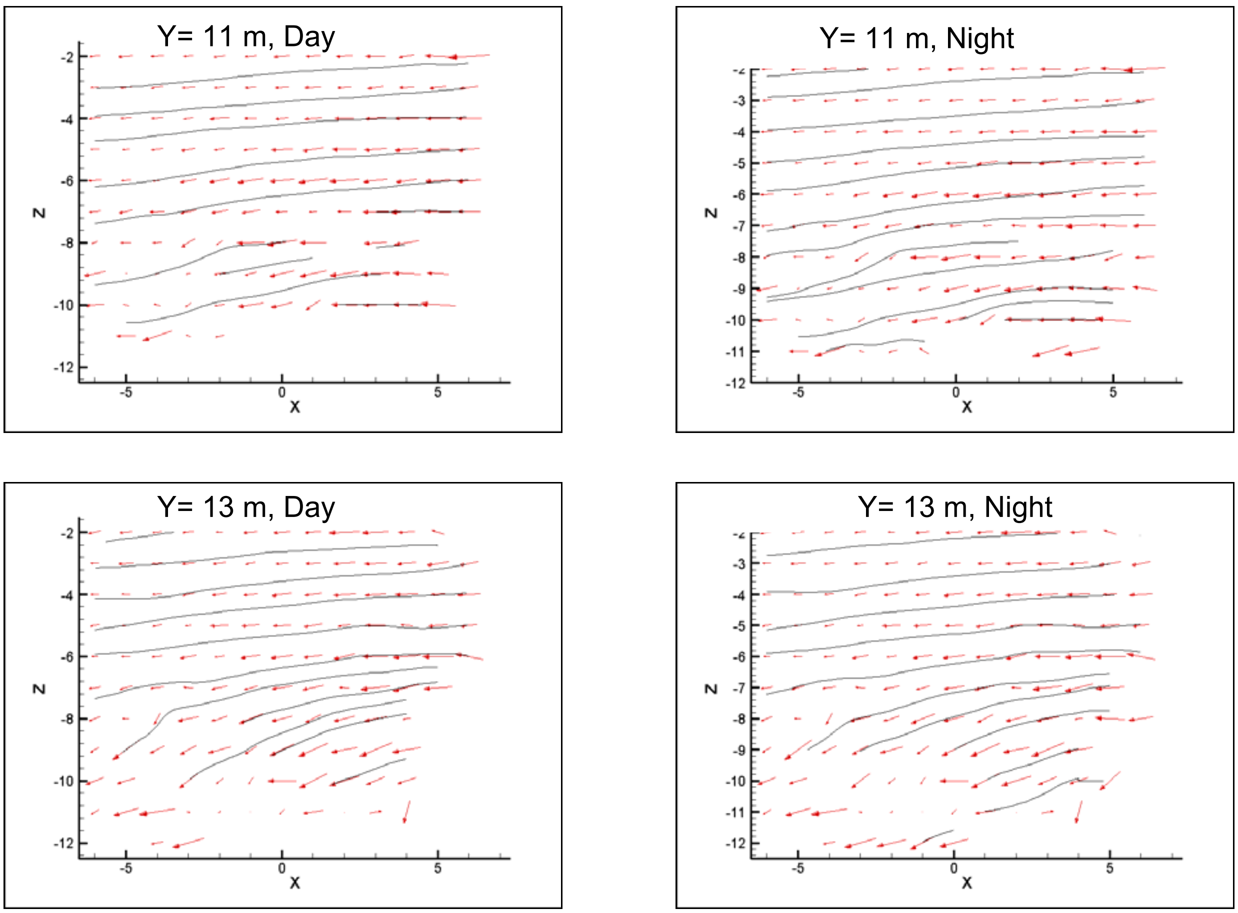


Figure 5.6. Fish Velocity Plots Comparing Two Vertical Slices near MU 4-2 at the Edge of the J-Occlusion Extension during May 5 to June 16, 2002. (There were not enough data for separate spring and summer periods.) The Z-axis is depth and the X-axis is parallel to the dam (left is west and right is east). Above, Y= 11 m, and below, Y=13 m from the dam re: piernose at elevation 158 ft. Plot scale shows vector location in m, vector length relative to plot units in m/s. On the left are day and on the right are night ping-to-ping velocity vectors with streamtraces (black lines). The sonar tracker was located near the top edge of the J-occlusion extension (X=0, Y=11.4, Z=-13.2 m).

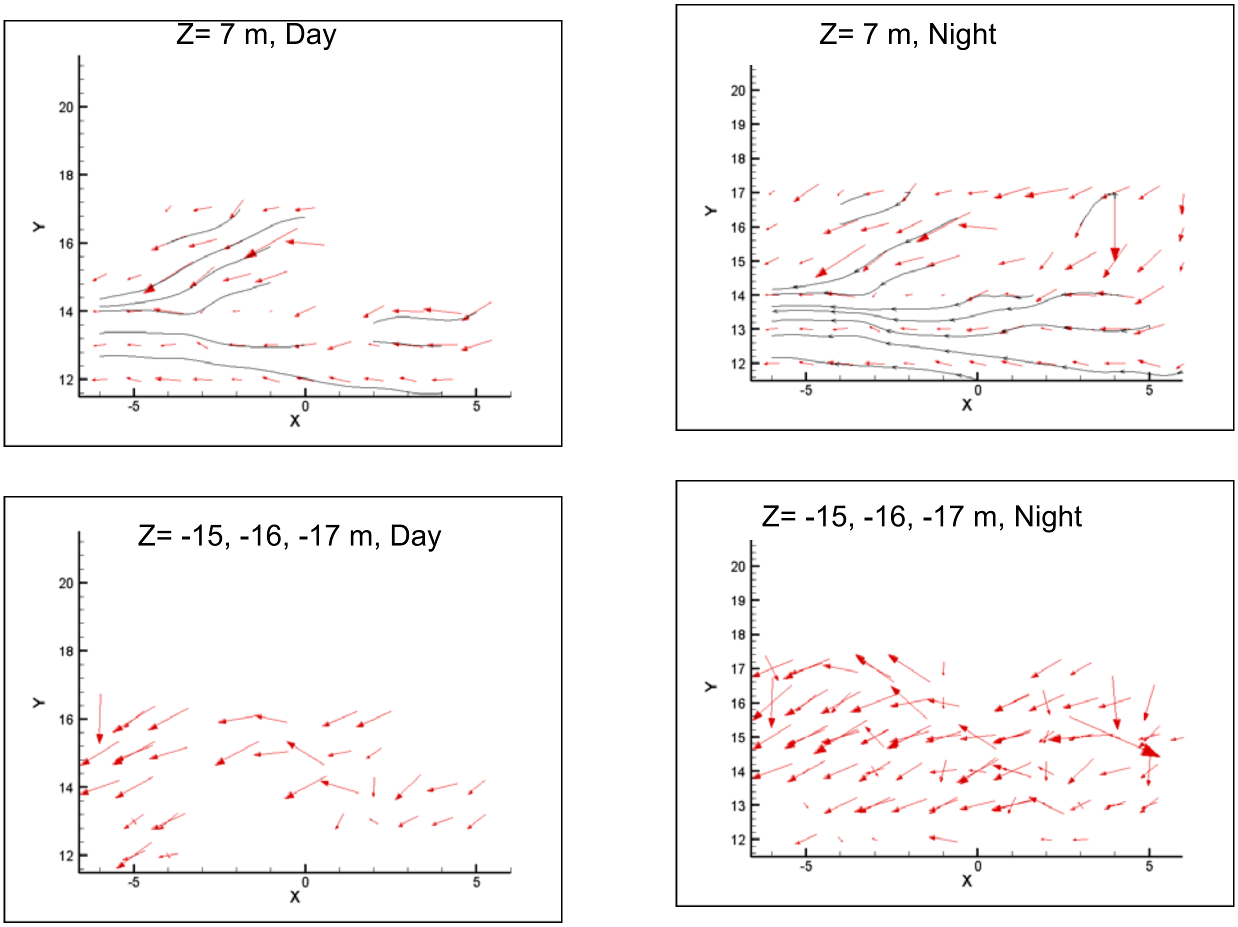


Figure 5.7. Fish Velocity Plots (side views) Comparing Horizontal Slices near Unit 4-2 at the Edge of the J-Occlusion Extension during May 5 to June 16, 2002. (There were not enough data for separate spring and summer periods.) X-axis is along the dam (left is west and right is east) and Y-axis is perpendicular to the dam (top is away and bottom is toward). Above, Z= -7 m, and below, Z= combined -15, -16, and -17 m from the surface at elevation 158 ft. Plot scale shows vector location in m, vector length relative to plot units in m/s. On the left are day and on the right are night ping-to-ping velocity vectors with streamtraces (black lines) only in the shallower 7-m slice. AFTS was located near the top edge of the J-occlusion extension (X=0, Y=11.4, Z=-13.2 m).

5.2.2 Direction of Movement Proportions

Fish track directionality at the edges of J-occlusions can be summarized using proportions of movement based on individual track regressions in each of the three dimensions (Table 5.2). Outside the J-occlusion at MU 4-2 the proportion of fish moving westward (83%) was generally much higher than observed in 2001 at the nearfield of the sluiceway (57%; Hedgepeth et al. 2002). Above a 14-m depth, the proportion of fish moving toward the dam was slightly less than those moving away. Below 14 m, fish moved downward and toward the dam. During the day, fish generally moved westward and downward.

In the majority of experimental blocks, fish marginally moved away from the dam during day. Movements to the west, marginally toward the dam, and downward were observed at night.

Table 5.2. Summary Mean Proportions for Direction of Movement Separately for Each Dimension for Each Condition, on the Reservoir Side of the J-Occlusion at MU 4-2 during May 5 to June 16, 2002. (There were not enough data for separate spring and summer periods.) Upper = above 14 m below surface.

	X		Y		Z	
	East	West	Away	Toward	Up	Down
All	0.17	0.83	0.52	0.48	0.40	0.60
Day	0.21	0.79	0.55	0.45	0.44	0.56
Night	0.09	0.91	0.47	0.53	0.33	0.67
Upper	0.18	0.82	0.53	0.47	0.41	0.59
Lower	0.03	0.97	0.15	0.85	0.15	0.85

Movements at the piernose between Units 4 and 5 were also overwhelmingly westward (81%) and somewhat downward (55%). In two different periods (May 1 to June 22 and June 28 to July 13), westward movement was similar for plates IN versus OUT (78% vs. 74% and 90% vs. 97%). During the first period, there was slightly less movement toward the dam (41% vs. 54%), while in the second period the movement was somewhat away (56% vs. 47%), with the J-occlusion plates IN versus OUT. More downward movement was observed during the second period with the J-occlusion deployed (72% vs. 58%).

Movement west was the dominant fate resulting from the Markov analysis no matter the season, day or night, or J-occlusion treatment (Figure 5.8). Westward movement, however, was stronger in spring than summer. Movement toward the dam was more common with the J-occlusions IN than OUT, especially in summer.

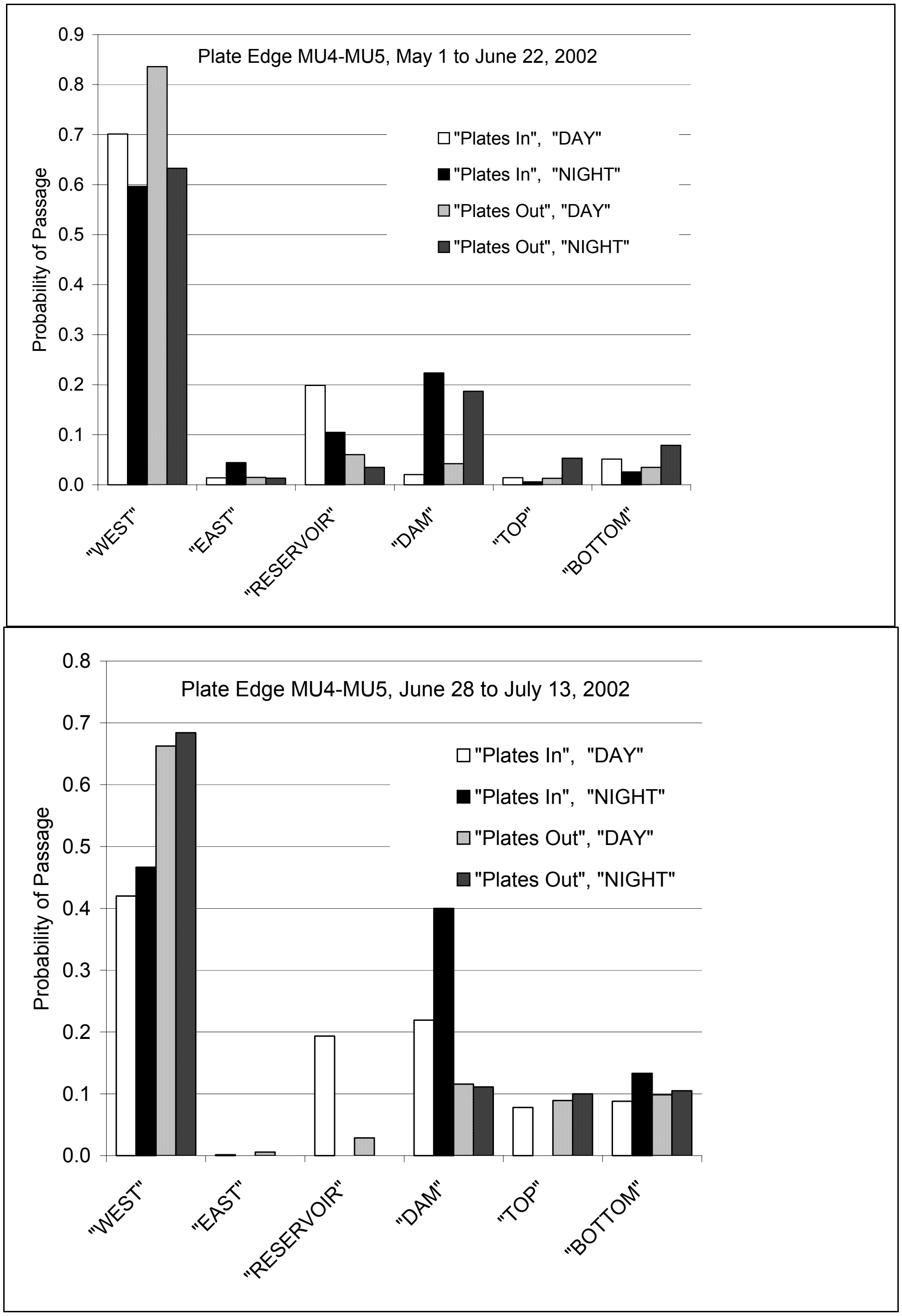


Figure 5.8. Fish Fates from the Sonar Tracker Sampling Volume at the Piernose between MU 4 and MU 5. Possible fates are west toward spillway, upstream or east, toward reservoir, toward the top or surface, and out the bottom of the sampling volume. The upper figure is passage for May 1-June 22, 2002; the lower figure is passage June 28-July13, 2002.

5.2.3 Vertical Distributions Near the J-Occlusion at MU 4-2

The depth distribution of fish upstream of the J-occlusion at Unit 4-2 was estimated using fish track positions and weighting based on volume sampled and number of pings tracked (see Appendix B). The vertical distribution showed a marked change during May 5 to June 16 (Figure 5.9). Average depth was 6.5 m (day) and 3.2 m (night) in Block 3. Average day depth became generally shallower while night depth became deeper. By Block 10, average depths were 5.6 m (day) and 4.9 m (night).

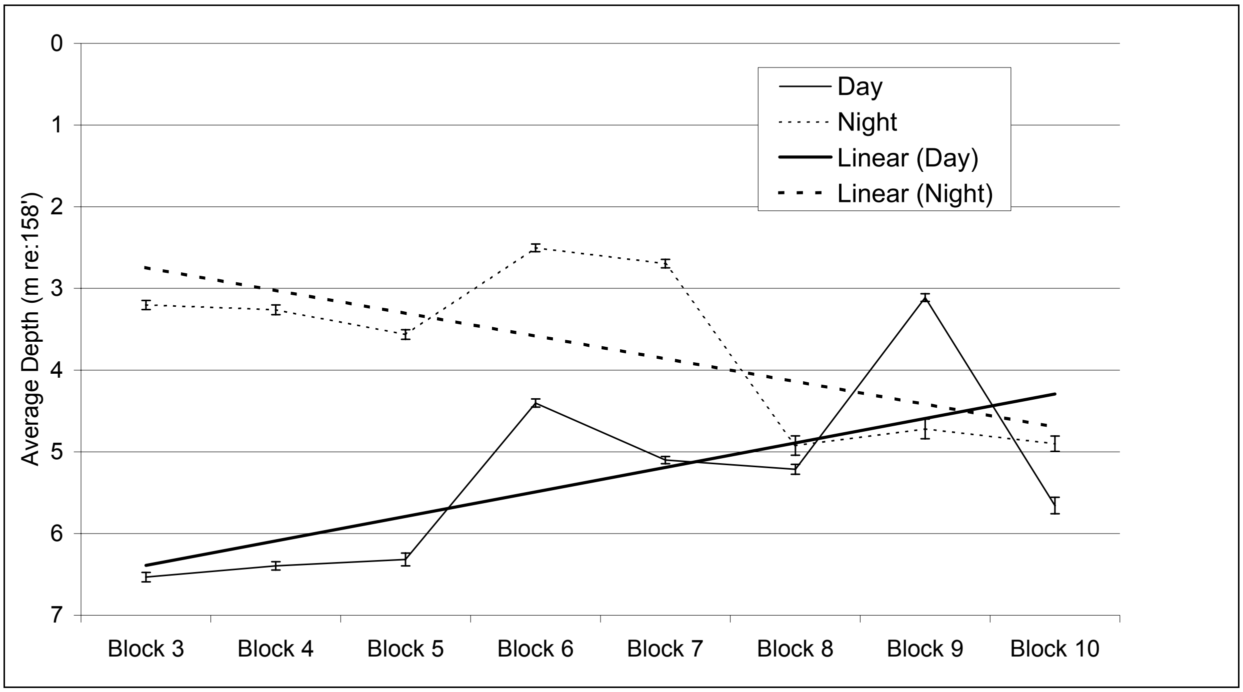


Figure 5.9. Average Depth of Fish Approaching J-Occlusion at Main Unit 4-2 from Data in Experimental Blocks 3-10 (May 5 to June 16) (Confidence intervals are two standard errors.)

Vertical distribution was also examined off the piernose at MU 3 and 4 using a split-beam transducer. There was no apparent difference in the vertical distributions between treatments for J-occlusions IN and OUT. Also, there was no consistent difference between day and night in vertical distribution.

5.3 Acoustic Camera Observations of Predators and Smolts

This section addresses Objective 9, which was to "record the presence/absence and behavior of juvenile salmon and predator fishes in the vicinity of the J-block occlusions and at gaps between adjacent J-block occlusions." In addition, we present data on predators, the presence of shad, predator/smolt co-occurrence, fish behavior in front of trashracks, and fish behavior upstream of the sluiceway entrances.

5.3.1 Predators

The total number of predator fish detected during the spring and summer study periods was similar (Figure 5.10). Predator fish at Sluice 1-3 were most likely to be observed near the sluice entrance staging just below the sill or near the adjacent pier noses. This occurred regardless of the presence of J-occlusions. A common staging location at both sampling locations was very near the piernoses. In front of MU 3 and 4 with the plates in, the predators had more freedom of movement and tended to roam back and forth along the powerhouse. Only in a few instances were predator fish seen swimming near the plate floor or near the gap. In several instances predators were observed actively pursuing smolts or groups of smolts and in at least one instance clearly consumed a smaller fish (Figure 5.11).

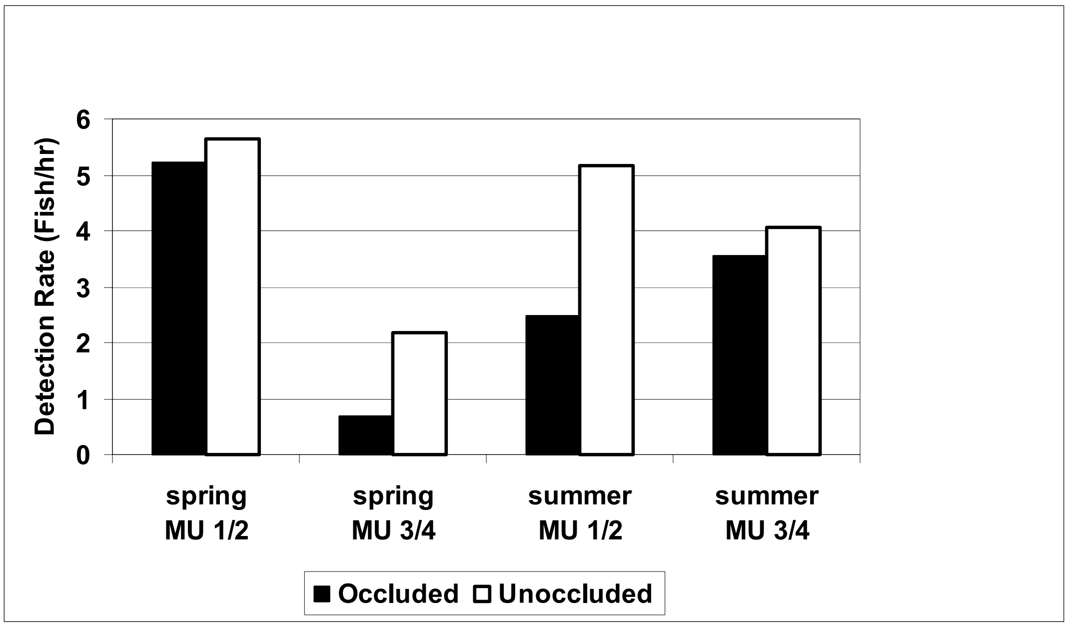


Figure 5.10. Number of Predator Fish Detections at Sample Location MU 1/2 and 3/4 during the J-Occlusions IN (occluded) and OUT (unoccluded) Treatments

5.3.2 Shad

The American shad (*Alosa sapidissima*) is a non-native anadromous clupeid. The run timing, body size and shape, and schooling behavior of this fish makes species discrimination via the DIDSON possible. A total of 43 shad were detected during the summer period. Large schools of shad (eight or more fish) were also observed on July 10-11 in front of MU 3 and 4.

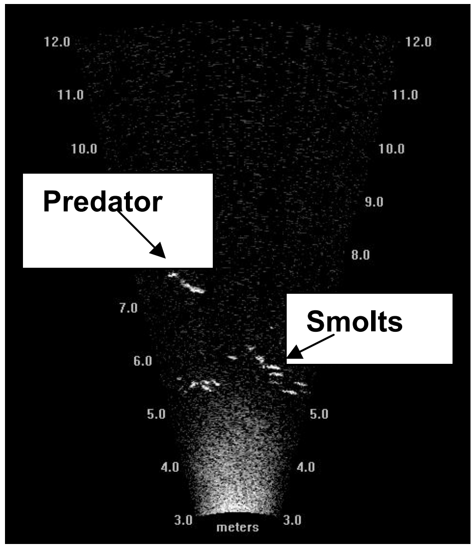


Figure 5.11. Simultaneous Observation of Predator and Smolts

5.3.3 Predator and Prey Co-Occurrence

Predators and prey were detected near the powerhouse at the same time. This association was true for the entire study (Figure 5.12) and supports the assignment of these observations as predators. The predator observation rate increased as the smolt observation rate increased.

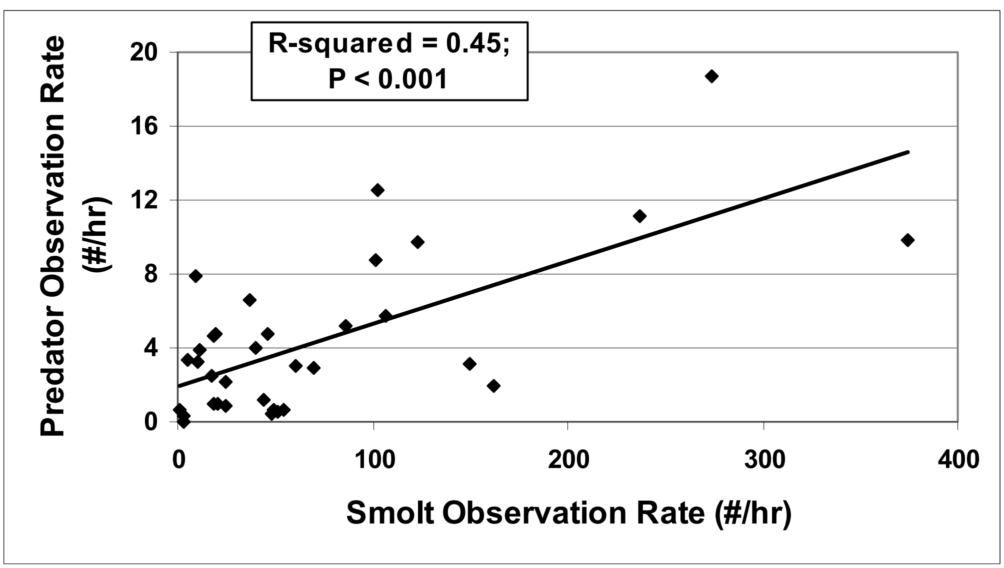


Figure 5.12. Relationship between Smolt and Predator Observation Rates. Both treatments and seasons were pooled.

5.3.4 Fish Behavior at the Trashrack

Direct observations of fish as they approached the trashrack during the OUT treatment revealed a consistent behavior pattern (Figure 5.13). Fish did not simply approach and pass through the trashrack. Instead, fish consistently hesitated in front of the trashrack, with the trashrack functioning as a behavioral barrier. The data also showed that the water velocities were well within the swim capacity of both smolts and predators. Although this behavioral phenomenon is well documented, as are the water velocities, it has not been observed *in situ* at a mainstem hydroelectric project before. Some of the fish observed holding in front of the trashracks, however, did eventually pass through the trashrack and enter the intake.

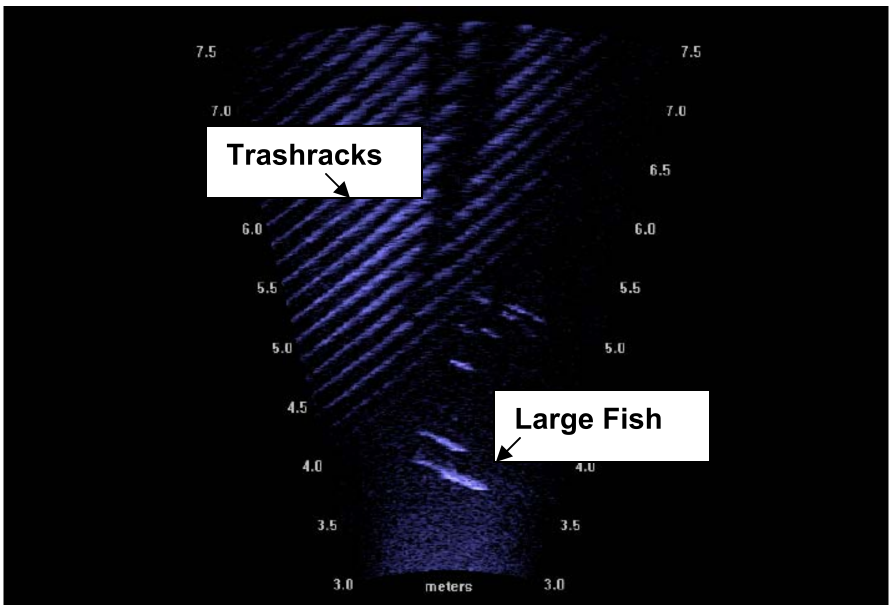


Figure 5.13. Large Fish in Front of the Trashrack. These fish were positively rheotactic and actively avoided passage through the trashrack.

5.3.5 Ice and Trash Sluiceway Entrance

All of the observed smolts that entered the ice and trash sluiceway passed through the center of the intake. They appeared to avoid the piernose wall. While detailed hydraulics at this scale were not available, it appeared that water velocities were also low in this region. The pattern of water velocities was consistent with flow through an open channel with progressively faster flows nearer the middle of the entrance. In addition, smolts were not committed to passage via the ice and trash sluiceway from the forebay. Smolts were free to enter and leave the area of the forebay directly in front of the open ice and trash sluiceway. Smolts were entrained in sluice flow just over the sill at the downstream edge of the trashrack.

6.0 Discussion

Passage efficiency and effectiveness estimates for 2002 were lower than in 1999 and 2000 when similar methods were employed at The Dalles Dam (Table 6.1). (2001 data are not included here because there was little spill in this low-flow year.) The National Marine Fisheries Service (2000) summarized the performance of spill for yearling fish at The Dalles Dam. Using their Equation 1 (p. 6), effectiveness would be 1.9 for 37% spill, which is higher than the 1.2 we estimated for 2002. Clearly, proportionately more fish were passing through powerhouse turbines in 2002 than in previous studies, but why?

Table 6.1. Discharge Data and Hydroacoustic Estimates of Passage Efficiencies for Spring and Summer Study Periods in 1999, 2000, and 2002. 2001 is not included because it was an abnormally low flow year with a relatively small amount of spill. Data for 1999 and 2000 are from Ploskey et al. 2002.

	Spring			Summer		
	1999	2000	2002	1999	2000	2002
Mean Total Discharge (kcfs)	286	235	234	320	193	300
Spill Discharge Proportion	0.47	0.40	0.37	0.46	0.40	0.38
Fish Passage Efficiency	0.79	0.92	0.69	0.79	0.81	0.50
Spill Efficiency	0.66	0.86	0.45	0.66	0.74	0.38
Sluice Efficiency	0.13	0.06	0.25	0.13	0.07	0.11
Spill Effectiveness	1.4	2.2	1.2	1.4	1.9	1.0
Sluice Effectiveness	8.6	3.2	13.0	8.6	3.3	7.6

Dam operations, specifically powerhouse loading, can affect fish passage (Thorne and Johnson 1993). In 2002, turbine priority was from west to east (MU 1 to MU 22; highest to lowest) with MU 1-5 block loaded. This operation was different than previous years when typically one of each pair of adjacent units (MU 1-2, 3-4, etc.) was operated with priority from west to east and back again as necessary to load the second unit of a pair. Block loading west-end units in 2002 could have extended the effect of powerhouse flows further across the forebay than more uniform loading of previous years (L. Ebner, Corps of Engineers Portland District, pers. comm.). The result could have been less passage at the spillway and more passage at the powerhouse. The design of any future studies of fish distribution in the forebay should account for powerhouse operations.

Dam operations also affected the migration of subyearling salmon in summer 2002. Passage into the eastern portion of the powerhouse (MU 11-22) was noticeable as eastern units were operated more in summer than spring. Subyearling salmon are typically more shoreline-oriented than yearling fish (Dauble et al. 1989; Bennett et al. 1998), although radio telemetry data indicate that they first encounter the east (upstream) end of The Dalles Dam powerhouse at similar rates as yearling fish (Sheer et al. 1997; Holmberg et al. 1996). Subyearling chinook salmon also generally migrate deeper in the water column (Johnston et al. 2000) and are smaller (Martinson et al. 2002) than their yearling counterparts.

Another interesting difference between passage in 2002 and in previous years was the relatively high proportion of juvenile sockeye salmon in the emigration this year. These Upper Columbia River sockeye reared in Lake Osoyoos (~75%) on the Okanogan River or in Lake Wenatchee (~25%) on the Wenatchee River (very few would have come from the Snake River) and were from the 2000 brood year. In 2000, passage of adult sockeye past Rock Island Dam was among the highest on record (Fish Passage Center 2001). Subsequently, juvenile sockeye were the second most common outmigrant at the John Day smolt monitoring facility in spring 2002 (25%). The same trend was seen in data from the smolt monitoring facility at McNary Dam (http://www.cqs.washington.edu/DART/). Juvenile sockeye salmon tend to migrate deeper in the water column than all other yearling migrants especially at night. For example, 37% of the sockeye and 20% of the yearling chinook were caught below the 75-ft depth in a vertical array of fyke nets spanning the entire water column (130 ft) at Wells Dam during night in 1985 (Johnson et al. 1992). During day, vertical distribution was much shallower (6% of the fish below 75 ft deep), but sockeye were still deeper than yearling chinook salmon. Another important fact about juvenile sockeye salmon is that they are the smallest yearling migrants. For example, fish length averaged 100 to 150 mm at the John Day facility in 2001 (Martinson et al. 2002). The relatively high proportion of juvenile sockeye is important to passage at The Dalles Dam because their small size and relatively deep vertical distribution might make them more vulnerable to powerhouse flows in the forebay. Collectively, dam operations and species composition might explain why passage efficiencies were lower in summer than spring 2002 at The Dalles Dam. These factors might also have affected performance of the J-occlusions.

Our data indicated that the J-occlusions were not particularly successful at reducing turbine entrainment. There were some positive findings in spring with passage into MU 1-4 higher during the IN treatment than the OUT treatment in 5 of 7 blocks with the results statistically significant for night ($P = 0.03$). However, the J-occlusions did not perform well for subyearling fish in summer. Reasons for this may be related to the same factors mentioned above: small, relatively deep yearling sockeye and subyearling chinook salmon emigrants. These biological factors, coupled with the hydraulic effect of the J-occlusions and powerhouse operations on forebay flows, may explain the somewhat less-than-ideal performance of the J-occlusions. The downward component of flow into the turbines caused by the J-occlusions (Figure 2.3), especially, may have entrained more of the smaller, deeper smolts than expected. This was indicated in the fish movement data at MU 4 (Figure 5.8). Furthermore, larger migrants such as steelhead were observed holding just upstream of the trashracks of operating units. For fish that might be able to avoid turbine intake flows, J-occlusions might be inconsequential.

Predator fishes at MU 1/2 were most likely to be found near the sluiceway entrance staging just below the sill or near the pier nose. At MU 3/4, predators were mostly observed roaming back and forth along the powerhouse near the intake trashracks with J-occlusions OUT or near the occlusion plates with J-occlusions in. Predator abundance was similar between seasons and IN and OUT treatments. Thus, predators seemed to be present in the forebay near the face of the dam irrespective of the J-occlusions.

Horizontal distribution was related to project operations. At the powerhouse, there was higher passage into the eastern units in summer than spring because units there were operated more in summer. It may be beneficial to summer migrants if the east-end sluice gates are operated in the future.

The hydroacoustic results of J-occlusion performance reported herein differ somewhat from the radio telemetry results reported by Beeman et al. (2002). They found that fish passage efficiency was significantly higher with the J-occlusions IN than OUT for radio-tagged yearling and subyearling chinook salmon, but not steelhead. (At this time, MU 1-4 passage apparently has not been used as a response variable in the radio telemetry analysis.) Differences in our respective findings could be related to the fish size and species composition factors mentioned above, i.e., the populations sampled differed between the two techniques.

In any event, the hydroacoustic data indicate that the J-occlusions are not a straightforward means to protect smolts at The Dalles Dam. The 2002 findings were consistent with previous studies in that the J-occlusions might perform well under certain conditions for certain fish, but not others. Given mixed performance to date for turbine intake occlusion devices, cost should influence the decision about whether to proceed with a full complement of J-occlusions at The Dalles Dam.

7.0 Conclusions and Recommendations

We reached the following conclusions from the hydroacoustic evaluation at The Dalles Dam in 2002:

1. Fish passage and spill efficiencies were lower than in previous studies.

2. Subyearling passage in the eastern half of the powerhouse was noticeable.

3. Except for nighttime in spring, turbine intake occlusion did not significantly reduce turbine entrainment in either spring or summer study periods.

4. Predators were present near the face of the dam irrespective of the presence of the J-occlusion structures.

If the region decides that spillway improvements alone will not suffice at The Dalles Dam, then we recommend work to:

1. Develop a means to protect fish at the powerhouse beyond existing sluice operation.

2. Perform an alternatives study for powerhouse bypass and/or diversion.

3. Model forebay flow patterns and relate them to dam operations.

4. Obtain basic data on smolt approach and distribution in the forebay.

5. Investigate operation of east-end sluice gates to pass subyearlings.

6. Examine use of overhead lights to enhance sluice passage.

8.0 References

Beeman, J., H. Hansel, and J. Phelps. 2002. *Estimate fish, spill, and sluiceway passage efficiencies of radio-tagged juvenile salmonids relative to operation of J-design intake occlusion plates at The Dalles dam in 2002.* Preliminary report of research by U.S.G.S. Biological Resources Division submitted to the U.S. Army Corps of Engineers, Portland, Oregon. October 10, 2002.

Belcher, E., H. Dinh, D. Lynn. and T. Laughlin. 1999. "Beamforming and Imaging with Acoustic Lenses in Small, High-Frequency Sonars." *Proceedings of Oceans 1999 Conference*, September 13-16, Seattle, Washington, pp. 1495-1499.

Bennett, D.H., T. Dresser, Jr., and M.A. Madsen. 1998. *Habitat Use, Abundance, Timing, and Factors Related to the Abundance of Subyearling Chinook Salmon Rearing along the Shorelines of Lower Snake River Reservoirs.* Final completion report by University of Idaho submitted to U.S. Army Corps of Engineers, Walla Walla, Washington.

BioSonics, Inc. 1996. *Hydroacoustic Evaluation and Studies at The Dalles Dam, Spring/Summer 1996. Volume 2 - Smolt Behavior.* Draft final report by BioSonics, Inc submitted to U.S. Army Corps of Engineers, Portland, Oregon. November 15, 1996.

BioSonics, Inc. 1998. *DT/DE Series User's Manual Version 4.02*. BioSonics, Inc., Seattle Washington.

Brookner, E. 1998. *Tracking and Kalman Filtering Made Easy*. John Wiley and Sons, New York.

Carlson, T. J., W. C. Acker, and D. M. Gaudet. 1981. *Hydroacoustic assessment of downstream migrant salmon and steelhead at Priest Rapids Dam in 1980.* Final report by Applied Physics Laboratory, University of Washington submitted to Grant County PUD, Ephrata, WA. APL-UW 8016.

Dauble, D.D., T.L. Page, and R.W. Hanf, Jr. 1989. "Spatial Distribution of Juvenile Salmonids in the Hanford Reach, Columbia River." *Fishery Bulletin* 87(4): 775-790.

Dauble, D. D., S. M. Anglea, and G. E. Johnson. 1999. *Surface Flow Bypass Development in the Columbia and Snake Rivers and Implications to Lower Granite Dam.* Final Report July 21, 1999 submitted by Battelle to U.S. Army Corps of Engineers, Walla Walla, Washington.

Efron B. and R. Tibshirani. 1993. *An Introduction to the Bootstrap.* Chapman and Hall.

ENSR. 2001. *Three-Dimensional Computational Fluid Dynamics (CFD) Modeling of the Forebay of The Dalles Dam, Oregon.* Final Report by ENSR International submitted to U.S. Army Corps of Engineers, Portland, Oregon. June 2001. Document Number 3697-006-320.

Fish Passage Center. 2001. *Fish Passage Center Annual Report 2000.* Final report submitted to the Bonneville Power Administration, Portland, Oregon. BPA Project No. 94-033. June 2001.

Hedgepeth, J. and J. Condiotty. 1995. "Radar Tracking Principles Applied for Acoustic Fish Detection." Poster Presentation, *ICES International Symposium on Fisheries and Plankton Acoustics,* Aberdeen Scotland, 12-16 June 1995, Book of Abstracts, page 10.

Hedgepeth, J., D. Fuhriman and W. Acker. 1999. Fish Behavior Measured by a Tracking Radar-Type Acoustic Transducer Near Hydroelectric Dams." In *Innovations in Fish Passage Technology*. Ed. M. Odeh, pp. 155-171, American Fisheries Society, Bethesda, MD.

Hedgepeth, J.B., D. Fuhriman, G.M.W. Cronkite, Y. Xie, and T.J. Mulligan. 2000. "A Tracking Transducer for Following Fish at Close Range." *Aquat. Living Resour*. 13(5): 305-311.

Hedgepeth, J. B., G. E. Johnson, A. E. Giorgi, and J. R. Skalski. 2002. *Sonar tracker evaluation of fish movements relative to J-occlusions at The Dalles Dam in 2001.* Final report submitted by Battelle to U.S. Army Corps of Engineers, Portland District. March 8, 2002.

Holmberg, G.S.; R.S. Shively, H.C. Hansel, T.L. Martinelli, M.B. Sheer, J.M. Hardiman, B.D. Liedtke, L.S. Blythe, and T.P. Poe. 1996. *Movement, Distribution, and Behavior of Radio-Tagged Juvenile Chinook Salmon in John Day, The Dalles, and Bonneville Dam Forebays, 1996.* Annual report of research U.S.G.S. Biological Resources Division submitted to the U.S. Army Corps of Engineers, Portland District.

Johnson, G.E., C.M. Sullivan, and M.W. Erho. 1992. "Hydroacoustic Studies for Developing a Smolt Bypass System at Wells Dam." *Fisheries Research* 14:221-237.

Johnson, G.E., J.B. Hedgepeth, A.E. Giorgi, and J.R. Skalski. 2001. *Evaluation of Smolt Movements Using an Active Fish Tracking Sonar at the Sluiceway Surface Bypass, The Dalles Dam, 2000.* Final report by BioAnalysts, Inc. submitted to the U.S. Army Corps of Engineers, Portland District. September 30, 2001.

Johnson, R. L., D. R. Giest, R. P. Mueller, R. A. Moursund, J. Hedgepeth, D. Fuhriman, and A. Wirtz. 1998. *Behavioral acoustic tracking system (BATS)*. Final report submitted by Battelle to U.S. Army Corps of Engineers, Walla Walla, Washington. January 1998.

Johnston, S., P. Nealson, and J. Horchik. 2000. *Hydroacoustic studies at John Day Dam, spring/summer 1999.* Draft report by submitted Hydroacoustic Technology, Inc. to the U.S. Army Corps of Engineers, Portland District. March 29, 2000.

Kumagai, K. K., Ransom, B. H., and Sloan, H. A. 1996. *Effectiveness of a Prototype Surface Flow Attraction Channel for Passing Juvenile Salmon and Steelhead Trout at Wanapum Dam during Summer,* Final report submitted Hydroacoustic Technology, Inc. to Grant County PUD, Ephrata, WA.

MacLennan, D. N. and E. J. Simmonds. 1992. *Fisheries Acoustics.* Chapman and Hall. London, England.

Martinson, R., J. Kamps, G. Kovalchuk, and D. Ballinger. 2002. *Monitoring of donwstream salmon and steelhead at federal hydroelectric facilities -- 2001.* Annual Report submitted to Bonneville Power Administration, Portland, Oregon. February 2002.

Moursund, R.A., K.D. Ham, P.S. Tizler, R.P. Mueller, G.E. Johnson, J.B. Hedgepeth, and J.R. Skalski. 2002. *Hydroacoustic Evaluation of Fish Passage at The Dalles Dam in 2001.* Final report submitted to U.S. Army Corps of Engineers, Portland, Oregon. June 2002.

Nagy, W.T. and M.K. Shutters. 1995. *Hydroacoustic Evaluation of Surface Collector Prototypes at The Dalles Dam, 1995.* Draft report by the Fisheries Field Unit submitted to U.S. Army Corps of Engineers, Portland, Oregon.

National Marine Fisheries Service. 2000. "Re-initiation of Consultation on Operation of the Federal Columbia River Power System, including the Juvenile Fish Transportation Program, and 19 Bureau of Reclamation Projects in the Columbia Basin." *Biological Opinion.* December 21, 2000, National Marine Fisheries Service, Northwest Region, Seattle, Washington.

Nichols, D.W. and B.H. Ransom. 1980. *Development of The Dalles Dam Trash Sluiceway as a Downstream Migrant Bypass System for Juvenile Salmonids.* Final report by Oregon Department of Fish and Wildlife submitted to U.S. Army Corps of Engineers, Portland, Oregon.

Ploskey G.R., T. Poe, A.E. Giorgi, and G.E. Johnson. 2002. *Synthesis of Radio Telemetry, Hydroacoustic, and Survival Studies of Juvenile Salmon at The Dalles Dam (1982-2000).* Final report submitted by Battelle to U.S. Army Corps of Engineers, Portland District. PNWD-3131.

Ploskey, G., B. Nagy, L. Lawrence, M. Hanks, C. Schilt, P. Johnson, G. Johnson, D. Patterson, and J. Skalski. 2001. *Hydroacoustic Evaluation of Juvenile Salmon Passage at The Dalles Dam: 1999.* Final report submitted by WES to U.S. Army Corps of Engineers, Portland, Oregon. ERDC/EL TR-01-11.

Ploskey, G. R., L. R. Lawrence, P. N. Johnson, W. T. Nagy, and M. G. Burczynski. 1998. *Hydroacoustic evaluations of juvenile salmonid passage at Bonneville Dam including surface-collection simulations.* Final report submitted by WES to U.S. Army Corps of Engineers, Portland, Oregon. EL-98-4.

Sheer, M.B., G.S. Holmberg, R.S. Shively, H.C. Hansel, T.L. Martinelli, T.P. King, C.N. Frost, T.P. Poe, J.C. Snelling, and C.B. Schreck. 1997. *Movement and Behavior of Radio-Tagged Juvenile Spring and Fall Chinook Salmon in The Dalles and John Day Dam Forebays, 1995*. Final report by U.S.G.S. Biological Resources Division submitted to the U.S. Army Corps of Engineers, Portland, Oregon.

Taylor, H. and S. Karlin. 1998. *An Introduction to Stochastic Modeling*. 3rd ed. Academic Press. San Diego, California.

Thorne, R. and G. Johnson. 1993. "A review of hydroacoustic studies for estimation of salmonid downriver migration past hydroelectric facilities on the Columbia and Snake rivers in the 1980s." *Reviews in Fisheries Science* 1:27-56.